Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of	)	
	)	
Policies Regarding Mobile Spectrum Holdings	)	WT Docket No. 12-269
	)	

REPLY COMMENTS OF AT&T INC.

David L. Lawson
James P. Young
C. Frederick Beckner III
Christopher T. Shenk
Sidley Austin LLP
1501 K Street, N.W.
Washington, D.C. 20005
(202) 736-8000

Michael P. Goggin
Gary L. Phillips
Peggy Garber
AT&T Inc.
1120 20th Street, N.W.
Washington, D.C. 20036
(202) 457-2055

Attorneys for AT&T Inc.

January 7, 2013

TABLE OF CONTENTS

INTRODUCTION AND SUMMARY 1

I. INSTEAD OF REPLACING ITS SPECTRUM SCREEN WITH SPECTRUM CAPS, THE COMMISSION SHOULD APPLY THE SCREEN WITH GREATER PREDICTABILITY AND TRANSPARENCY. 7

A. The Commenters Overwhelmingly Support Retention of a Spectrum Screen Set at Least as High as One-Third of Suitable and Available Spectrum. 8

B. The Screen Should Once Again Function as a Safe Harbor, and the FCC Should Update the Spectrum Included Within the Screen in Annual Rulemakings. 13

C. The Commission Should Make Appropriate Adjustments to the Spectrum Included in the Screen, Including Counting the BRS/EBS Spectrum that is Already Being Used for the Provision of Mobile Broadband Services. 16

II. PROPOSALS TO ADOPT SCREENS THAT WOULD GIVE GREATER WEIGHT TO SPECTRUM BELOW 1 GHz SHOULD BE REJECTED. 22

A. The Proposed Weighting Schemes Are Fundamentally Flawed Both as a Matter of Economics and as a Matter of Wireless Engineering. 24

B. Each of the Three Proposed Weighting Schemes Suffer From Additional Flaws That Preclude It From Being Adopted. 27

III. VARIOUS OTHER PROPOSED MODIFICATIONS TO THE SPECTRUM SCREEN ANALYSIS SHOULD BE REJECTED. 37

A. The Commission Should Reject T-Mobile’s Self-Serving and Arbitrage-Friendly Proposal to Adopt a Cap for Auctions But Allow a Screen for Secondary Market Transactions. 38

B. Free Press’s “Three-Stage Analytical Approach” Is Inconsistent With Sound Economics and Would Create Enormous Marketplace Uncertainty. 42

C. The Commission Should Not Engraft an “Efficiency” Analysis as an Adjunct to Its Existing Approach. 44

D. The Commission Should Not Adopt a Separate National Screen. 46

IV. THE COMMISSION’S PROPOSED ATTRIBUTION RULES SHOULD APPLY PROSPECTIVELY TO FUTURE SPECTRUM ACQUISITIONS, NOT RETROACTIVELY TO EXISTING SPECTRUM HOLDINGS. 47

A. There Is No Support for the Proposed 10 Percent Attribution Threshold or Singling Out AT&T for Differential Treatment. 47

B. The Commission Should Apply Any New Restrictions on Spectrum Holdings Only to Future Transactions and on a Competitively Neutral Basis. 49

CONCLUSION...50

Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of	)	
	)	
Policies Regarding Mobile Spectrum Holdings	)	WT Docket No. 12-269
	)	

REPLY COMMENTS OF AT&T INC.

AT&T Inc. ("AT&T") respectfully submits its Reply Comments in response to the Commission's September 28, 2012, Notice of Proposed Rulemaking in WT Docket No. 12-269.[1]

INTRODUCTION AND SUMMARY

The U.S. wireless marketplace is among the most vigorously competitive in our national economy. In the midst of a prolonged and deep national recession, it has generated billions of dollars of investment capital, produced millions of jobs, and spawned a breathtaking array of innovative new consumer products and services. This wireless success story is due in no small measure to the Commission's longstanding recognition that a light touch approach to wireless regulation best promotes competition, innovation, and investment.

Not surprisingly, however, some marketplace participants would like the Commission to adopt more intrusive regulations to tip the competitive scales. They want the Commission to rig its spectrum aggregation rules to ensure their own success regardless of the decisions they make or the capital they risk. This is the age-old regulatory game that has been played ever since the advent of competition in telecommunications markets. It is a game that some wireless providers

[1] Notice of Proposed Rulemaking, *Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269, FCC 12-119 (rel. Sept. 28, 2012) ("*Notice*").

have now embraced despite—or perhaps because of—the intense competition that characterizes the U.S. wireless marketplace.

For example, Sprint, which controls double the spectrum as any other carrier, contends that most of its spectrum should be excluded altogether from the spectrum aggregation screen, but that the Commission should count all of AT&T's and Verizon's spectrum (and, indeed, double count much of it through an arbitrary "value" weighting scheme). T-Mobile, which chose to sit out the Commission's 700 MHz auction entirely and to forego secondary market spectrum opportunities, now wants the Commission to adopt spectrum rules designed to guarantee its ability to catch up on the cheap. And the Rural Telecommunications Group ("RTG") asks for spectrum caps so draconian they would require AT&T and Verizon to undertake immediate divestitures—unless, of course, AT&T and Verizon "volunteer" to be yoked with RTG's entire wish list of regulatory obligations that have no connection whatsoever to spectrum policy.

All of these self-serving proposals would reduce competition, innovation, and investment—indeed, their entire purpose is to reduce competitive pressures and investment incentives by tying the hands of providers that would otherwise compete and invest aggressively. As such, they would harm the public interest and undermine the goals of the Commission's spectrum policies, including the goal of keeping the United States on the leading edge of the global wireless industry.

Perhaps the most prevalent of the many baseless proposals among competitors of AT&T and Verizon is to weight sub-1 GHz "low band" spectrum more heavily in the spectrum screen. There is *no* economic or policy basis for any such spectrum-weighting scheme. The central premise of these proposals is that low band spectrum has superior propagation properties, which can, in some areas, decrease the deployment costs of a network. But in areas and in circumstances where the propagation properties of a given spectrum band decrease deployment costs, that spectrum will command a correspondingly higher price in the marketplace. Accordingly, the propagation qualities of low band spectrum do not in and of themselves provide any systematic marketplace advantage that can or should be captured in the screen.

Equally important, the only expert to file any submission on behalf of those advocating weighting proposals actually undercuts those proposals by demonstrating that low band spectrum often does *not* provide any deployment-related cost advantages. As Professor Peha shows, low-band spectrum's cost advantages disappear in the urban areas where most people live, because in those areas, low-band deployments must have cell sizes that are as small as those in high-band deployments to meet capacity needs.[2] And Professor Peha greatly overstates the impact of propagation differences in more rural areas through a number of unrealistic assumptions, including a base case in which the low-band provider is deploying cells with a radius of 80 kilometers—a deployment that would cover an area larger than the state of Connecticut and which (given the curvature of the earth) would require a tower taller than the Empire State Building.[3] In any event, as Professor Katz and Dr. Israel explain in their reply declaration, Professor Peha's own analysis confirms that higher high-band deployment costs are offset by lower high-band spectrum prices such that "there is no meaningful distinction between high- and low-frequency spectrum from the perspective of a foreclosure analysis."[4]

---

[2] Jon M. Peha Comments at 9.

[3] *See* Jeffrey H. Reed and Nishith D. Tripathi, *The Value of Spectrum: A Response to Professor Jon M. Peha's Paper*, at 13-14 (Jan. 7, 2013) ("Reed-Tripathi Paper") (attached hereto as Attachment A).

[4] *See* Mark A. Israel and Michael L. Katz, *Economic Analysis of Public Policy Regarding Mobile Spectrum Holdings: Reply Declaration*, ¶ 9 (Jan. 7, 2013) ("Katz-Israel Reply Decl.") (attached hereto as Attachment B) (Professor Peha's analysis "actually provides several pieces of evidence that strongly support the conclusion that the Commission should *not* implement a screen that

Apart from the lack of justification for a weighted screen, it is equally clear that any attempt to implement one would be wholly arbitrary. Professor Peha acknowledges that an accurate calculation of the relative costs of deploying mobile networks as a function of frequency is highly "complex," requires "too many factors to consider explicitly," and "can change rapidly."[5] He also asserts that different weightings would be appropriate for different areas of the country, but offers no approach for doing so.[6] And he agrees that "market value" weighting suffers from systemic problems: "the value bidders were willing to pay . . . may be quite different from the value today" and market prices depend on "many other things" in addition to the spectrum's "intrinsic value."[7]

As an alternative to weighting sub-1 GHz spectrum more heavily, some commenters propose a second, parallel screen that would apply *only* to sub-1 GHz spectrum—*i.e.*, the safe harbor would apply only if the applicant would hold less than approximately one-third of the total suitable spectrum *and* one-third of spectrum below 1 GHz. These proposals are not supported by a shred of economic or other support. A separate screen focused only on sub-1 GHz is nonsensical, because it effectively treats all suitable and available spectrum above 1 GHz as competitively *irrelevant*. Thus, under this test, a provider with a small fraction of all suitable and available spectrum but more than one-third of low band spectrum could trip the screen while a provider with substantially greater spectrum holdings would not. Not coincidentally, AT&T and Verizon would already exceed the proposed sub-1 GHz screens in a number of markets, and yet no commenter even attempts to show that such spectrum holdings have resulted in market

---

applies different weights to spectrum in different frequency bands suitable for mobile wireless service.").

[5] Peha Comments at 5-6.

[6] *Id.* at 11-12.

[7] *Id.* at 12.

foreclosure in any market. The reality, of course, is that numerous competitors are successfully using high band spectrum to offer state-of-the-art broadband services.

The flip side of proposals to weight spectrum held by AT&T and Verizon more heavily for purposes of the spectrum screen is Sprint's argument that most of its own spectrum should not count at all. In particular, Sprint argues that the Commission should continue to exclude more than 130 MHz of Sprint's 2.5 GHz spectrum. That argument is as audacious as it is convenient. Sprint holds *by far* the most broadband-ready spectrum. And both Sprint and its prospective parent, Softbank, are using 2.5 GHz spectrum today to provide state-of-the-art mobile wireless services. Indeed, Sprint has made quite clear that it is buying the rest of Clearwire "to maximize the value of Clearwire's 2.5 GHz spectrum and use it to increase Sprint's network capacity."[8] That in itself is proof positive that this spectrum must count in the Commission's screen, and none of Sprint's arguments to the contrary stand up to even the slightest scrutiny. The particular characteristics of this spectrum that Sprint/Clearwire cite—that it is leased, that portions of it are *authorized* (but almost never used) for high-powered uses, and the like—are equally true of other bands of spectrum that the Commission does include in the screen. It is long past time for the Commission to end this double standard that so blatantly favors Sprint.

Commenters also propose a variety of other modifications to the Commission's framework that should be rejected. For example, T-Mobile argues that the Commission should apply a spectrum cap in the auction context, but retain its screen approach for secondary market transactions. Under this scheme, the cap could prohibit carriers that have the highest-value use for a given block of spectrum from participating in an auction, thus clearing the way for T-

[8] Jimm Phillips, *Sprint's Buyout of Clearwire Unlikely to Face Major Regulatory Issues, Experts Say*, Communications Daily, Dec. 18, 2012, at 8 ("Communications Daily").

Mobile to acquire spectrum at a lower winning bid. But this proposal is not only transparently self-serving, it is also optimized for regulatory arbitrage. Once the auction is over the secondary market would be governed only by a *screen*, thus potentially allowing a spectrum speculator to sell the spectrum to the highest-value user, effectively transferring the profits from the Treasury to its own pocket. It is difficult to imagine a scheme better designed to benefit individual companies at the expense of the public. T-Mobile claims that such a scheme would increase "certainty," but what T-Mobile really means is that it wants the certainty that it will not have to compete with AT&T or Verizon in the upcoming auctions.

The remaining proposals are equally meritless. For example, Free Press's proposal to apply an "antitrust" review—in which the Commission would apply the Department of Justice/Federal Trade Commission "HHI" screen to the *input* market even when the HHI indicates no need for heightened review when applied to the *output* market—has no grounding in the facts or antitrust theory. Similarly, as Professor Katz and Dr. Israel have already explained, a separate national screen would be conceptually nonsensical given that spectrum can only be used in local markets, and such a screen would needlessly prevent beneficial entry that threatens no competitive harms.

Even though a number of commenters predictably seek to distort the operation of the Commission's spectrum screen to favor their own business interests, it is noteworthy that few commenters support replacing the spectrum screen with a spectrum cap, and for good reason. The ostensible advantage of a spectrum cap is greater certainty, but, as AT&T showed, a safe harbor screen coupled with case-by-case review of requests to exceed the screen, with that review utilizing clear principles transparently applied, provides the necessary certainty, and a cap would categorically preclude transactions that could promote competition and efficiency. The only dissenters are Free Press and RTG, who offer nothing but wild hyperbole to support their call for a return to rigid caps that would create disincentives for needed investment and innovation.

There is also wide agreement, at least in theory, that the Commission should regularly update the screen to include all spectrum suitable and available for mobile wireless services. AT&T agrees, and, as noted, that means the Commission can no longer exclude BRS and EBS spectrum.

And, although almost all commenters agree with the Commission that it should codify its attribution policy in a clear rule that should apply prospectively, there is general agreement that the Commission has not justified 10 percent as the threshold for attribution. It is exceedingly unlikely that any carrier could use a 10 percent minority interest to attempt a foreclosure strategy, and no commenter has offered any evidence to support such a rule. To the contrary, many providers note that such a low threshold is likely to prevent, or create disincentives for, beneficial investments that would pose no conceivable harm to competition.

ARGUMENT

I. INSTEAD OF REPLACING ITS SPECTRUM SCREEN WITH SPECTRUM CAPS, THE COMMISSION SHOULD APPLY THE SCREEN WITH GREATER PREDICTABILITY AND TRANSPARENCY.

There is broad consensus in the record that the Commission should not replace its spectrum screen with a regime based on hard caps because spectrum holdings that exceed the screen threshold may increase efficiency and promote competition, and the Commission should have the flexibility to assess holdings in excess of the screen on a case-by-case basis. There also is broad support for a screen threshold of at least one-third of the spectrum that is suitable and available for the provision of service ; indeed, the record provides considerable evidence that one-third is too low. And all parties support updating the spectrum that is included within the screen on a regular basis. Contrary to the self-serving claims of Sprint, Clearwire, and others, however, the Commission cannot lawfully continue to exclude BRS/EBS spectrum from the screen—spectrum that is not only "suitable" and "available" but actually *in use* to provide broadband services today. As shown below, the arguments for exclusion of that spectrum lost any validity they may have had years ago, and continued exclusion today of more than 130 MHz of suitable and available spectrum would maintain a blatant double standard that favors one competitor (Sprint) at the expense of others.

A. The Commenters Overwhelmingly Support Retention of a Spectrum Screen Set at Least as High as One-Third of Suitable and Available Spectrum.

There is almost universal opposition to the re-imposition of a spectrum cap. The commenters recognize that there is no single threshold that reliably identifies, across all markets, spectrum aggregations that pose an unacceptable risk of market foreclosure.[9] To the contrary, there are numerous instances in which, after scrutinizing proposed transactions that would result in spectrum holdings in excess of the screen, the Commission has concluded that those holdings would pose no risk to competition.[10] Accordingly, the record demonstrates that the public interest is best served by giving the Commission the flexibility to conduct a case-by-case review of holdings that exceed the screen threshold.[11]

---

[9] *See, e.g.*, Communications Liberty and Innovation Project ("CLIP") Comments at 10-11 ("Consumers would be better served if the FCC had the ability to approve beneficial transactions exceeding the benchmark that do not pose a risk of anticompetitive behavior"); Verizon Wireless Comments at 11-13; Clearwire Corporation Comments at 4-5; Sprint Nextel Corporation, Comments at 2 ("[t]he Commission's existing spectrum screen approach is not inherently flawed.").

[10] "In many cases, [the Commission] has determined that spectrum aggregation above the screen poses no risk of competitive harm because of the presence of existing and potential competitors, and has approved holdings that exceed the screen." Verizon Wireless Comments at 12.

[11] AT&T, Inc. Comments at 28-32; Mark A. Israel and Michael L. Katz, *Economic Analysis of Public Policy Regarding Mobile Spectrum Holdings*, (attached to Comments of AT&T Inc. filed in WT Docket No. 12-269) (Nov. 28, 2012) ("Katz-Israel Decl.") ¶¶ 17-24, 33-47; Katz-Israel

Two parties—Free Press and RTG—nonetheless urge the Commission to roll back the clock and scrap its spectrum screen in favor of a hard cap. They argue for a cap notwithstanding that the Commission concluded in 2001—*eleven years ago*—that "competition is now robust enough in CMRS markets that it is no longer appropriate to impose overbroad, *a priori* limits on spectrum aggregation that may prevent transactions that are in the public interest."[12] According to Free Press and RTG, the wireless marketplace is *less* competitive now than it was in 2001.[13]

This argument is both baseless and irrelevant. It is baseless because by any measure the wireless marketplace is far *more* competitive today than it was eleven years ago. The Commission's data show that competition has intensified substantially since the Commission adopted the safe harbor approach.[14] Among other things, capital expenditures have increased, innovation has exploded, prices have fallen, and the number of wireless connections has skyrocketed.[15]

Reply Decl. ¶ 2, 36-40; *cf. Notice* ¶ 13 (recognizing that acquiring more spectrum is often the most efficient way to add capacity needed to offer retail mobile wireless services). *See also* Verizon Wireless Comments at 12 (quoting Dr. Allan Shampine) ("Firms which cannot obtain sufficient spectrum to meet the demand by consumers for their services must ration their services by increasing price, reducing quality to stretch existing capacity further, or inefficiently substituting capital for spectrum, increasing costs and again raising the long-run competitive price. The price increases and reduced quality will impact not only the firm's own customers but wireless consumers generally"); MetroPCS Comments at 7-10; Clearwire Comments at 4.

[12] Report and Order, *2000 Biennial Regulatory Review – Spectrum Aggregation Limits for Commercial Mobile Radio Services*, 16 FCC Rcd. 22668, ¶ 50 (rel. Dec. 18, 2001) ("*Second Biennial Review Order*").

[13] Free Press Comments at 5; Rural Telecommunications Group ("RTG") Comments at 3-4.

[14] AT&T Comments at 25-26 (citing data); Verizon Wireless Comments at 38-39 (citing data); CTIA – The Wireless Association ("CTIA") Comments at 9 (citing data); *see also* Fifteenth Report, *Implementation of Section 6002(b) of the Omnibus Budget Reconciliation Act of 1993*, 26 FCC Rcd. 9664, ¶¶ 45-46 (Tables 6-7) (rel. June 27, 2011) ("*Fifteenth Wireless Competition Report*").

[15] CTIA Comments at 9; Verizon Wireless Comments at 39-40.

And it is irrelevant because the issue before the Commission in this proceeding is not which carriers are succeeding or not succeeding in the marketplace, but whether a spectrum cap is necessary to prevent a carrier from amassing so much of the available spectrum that its competitors would lack the spectrum they need to remain viable. Stated more broadly, the purpose of this proceeding should be to fashion spectrum policy that protects against market foreclosure, not, as Free Press and RTG would like, to prevent carriers from growing beyond a certain point by limiting their ability to obtain spectrum. That is a critical point, and it is a point that Free Press and RTG (as well as others) either fail to grasp or deliberately obfuscate.

As AT&T showed, foreclosure is *highly* unlikely in today's wireless marketplace because of the high cost of spectrum, the Commission's build-out requirements that preclude hoarding, and the existence of multiple entrenched facilities-based competitors with substantial spectrum holdings.[16] Regardless, the Commission has found repeatedly over the years that various spectrum holdings in excess of the screen posed no risk to competition and should be approved.[17] Neither Free Press nor RTG explains why less flexibility is appropriate public policy in these circumstances.

Second, there is also widespread support for maintaining the spectrum screen threshold at no less than its current level (approximately one-third of spectrum suitable for mobile wireless

[16] AT&T Comments at 15-19; Katz-Israel Decl. ¶¶ 27-32.

[17] *See, e.g.*, Memorandum and Opinion Order, *In the Matter of Sprint Nextel Corporation and Clearwire Corporation, Applications for Consent to Transfer Control of Licenses, Leases and Authorizations*, 23 FCC Rcd. 17570, ¶¶ 81-83 (rel. Nov. 7, 2008) ("*Sprint Nextel-Clearwire Order*"); Memorandum Opinion and Order, *Application of Aloha Spectrum Holdings Company LLC and AT&T Mobility II LLC Seeking FCC Consent for Assignment of Licenses and Authorizations*, 23 FCC Rcd. 2234, ¶¶ 11-12 (rel. Feb. 4, 2008) ("*Aloha Spectrum-AT&T Mobility II Order*"); Memorandum Opinion and Order, *Applications of Midwest Wireless Holdings, LLC and ALLTEL Communications, Inc.*, 21 FCC Rcd. 11526, ¶¶ 84-91 (rel. Oct. 2, 2006) ("*ALLTEL-Midwest Wireless Order*").

services).[18] Indeed, as AT&T demonstrated, if anything, the screen threshold should be raised above one-third.[19] There is no basis either for lowering the threshold—as suggested by RTG, which advocates 25 percent purely as a means to extort regulatory concessions on unrelated issues—or even, as MetroPCS and the Competitive Carriers Association ("CCA") suggest,[20] applying a heightened burden or presumption against above-screen acquisitions.

As Professor Katz and Dr. Israel demonstrated, the risk that a provider could use spectrum aggregation, even at levels well above one-third, to achieve market foreclosure in today's marketplace is remote at best.[21] The current screen has not enabled carriers to aggregate spectrum holdings that could be used to foreclose competition. To the contrary, "the current framework has enabled markets to flourish with multiple providers *and* next-generation, bandwidth-intensive deployments, all redounding to benefit consumers."[22]

Moreover, there has been a substantial increase in the amount of spectrum available to wireless providers since the Commission first adopted its one-third screen—meaning that in absolute terms there is substantially more spectrum available to other carriers even when a

---

[18] *See, e.g.*, CLIP Comments at 7-12; Sprint Comments at 10-13; Verizon Wireless Comments at 37-40. Several commenters implicitly endorse a screen of at least one-third in advocating that the Commission retain safe harbors. *See, e.g.*, Clearwire Comments at 4-5; CTIA Comments at 8-9; MetroPCS Communications Comments at 7-10. Notably, even Free Press, which advocates a hard cap, proposes it be set at "35 percent of the available spectrum in any local market." Free Press Comments at 14; *see also* T-Mobile USA, Inc. Comments at 8-13 (arguing for a cap of one-third useable spectrum for auctions but retaining the Commission's existing safe harbor approach for secondary market transactions).

[19] AT&T Comments at 48-54.

[20] MetroPCS Comments at 11-12; Competitive Carriers Association ("CCA") Comments at 16-17.

[21] Katz-Israel Decl. ¶¶ 26-32.

[22] Verizon Wireless Comments at 38.

carrier holds one-third of available spectrum.[23] At the same time, it is now clear that some carriers do not need a substantial share of spectrum to be significant competitors.[24] Although more established carriers may need more spectrum to serve larger legacy customer bases, new entrants can leapfrog existing competitors by deploying more spectrally efficient technologies (like LTE).[25] Indeed, as Professor Katz and Dr. Israel demonstrated empirically, carriers have been able to achieve significant shares of customers with relatively small percentages of the overall available spectrum.[26]

Given this compelling evidence that the current "one-third" threshold is too low, it would be patently arbitrary to lower the threshold, or to hold that any transaction that would increase a carrier's spectrum holdings above the Commission's existing threshold is presumptively anticompetitive. Instead, the Commission should retain or increase the current threshold and evaluate any spectrum holdings that exceed the screen to determine, without the bias of presumptions, whether those spectrum holdings would enable the carrier at issue to foreclose rivals from obtaining the capacity they need to compete.

RTG nonetheless urges the Commission to adopt a 25 percent spectrum cap and require "divestiture of excessive spectrum within 18 months" after adopting that cap.[27] But not only does RTG provide no factual support for its proposed 25 percent standard, it reveals its real

---

[23] Katz-Israel Decl. ¶¶ 60, 64.

[24] *Id.* ¶¶ 61-62 & Figure 1.

[25] *Id.* ¶ 60.

[26] *Id.* ¶ 62 & Figure 1.

[27] RTG Comments at 11. CCA, on the other hand, seeks to obtain a disparate regulatory advantage for its members by arguing that rural carriers should be given greater flexibility to go above the screen. CCA Comments at 17-18. Although AT&T agrees the current threshold is too low and many above-threshold transactions will not raise any legitimate competitive concerns, the Commission's spectrum policies must be applied in a competitively neutral manner and not as a tool to give an artificial regulatory advantage to certain groups of carriers.

motive is to abuse the screen to extract unrelated concessions. RTG proposes that carriers be allowed to retain existing spectrum above the "cap" so long as they agree to RTG's "wish list" of concessions: "the carrier must continually offer data roaming to any requesting carrier at commercially reasonable rates, terms and conditions"; "the carrier must offer its own customers devices that are fully interoperable (*i.e.*, the mobile device must work on all spectrum that is valuable and usable in that particular spectrum band, as well as any other spectrum band where that carrier offers services)"; and "any Tier I carrier . . . must work to ensure that mobile devices it sells its own customers are available on a non-exclusive basis to Tier II and III carriers who utilize the same technology as the Tier I carrier."[28] AT&T has addressed the merits of RTG's anti-consumer wish list in other proceedings and will not repeat those arguments here.[29] Suffice it to say that RTG's proposal represents a particularly stark attempt to link spectrum policy to wholly unrelated matters, and it should be categorically rejected by the Commission.

B. The Screen Should Once Again Function as a Safe Harbor, and the FCC Should Update the Spectrum Included Within the Screen in Annual Rulemakings.

Although there is no credible support in the record for reimposing spectrum caps, the Commission can and should take steps to bring greater predictability and transparency to its application of the spectrum screen. First and foremost, the Commission should restore the screen to its original function, which was to create a safe harbor for spectrum acquisitions that do not exceed the screen threshold. Until very recently, that is exactly how the screen functioned: spectrum aggregations that did not trip the screen were recognized to present no risk of

---

[28] *Id.* at 12.

[29] *See e.g.*, AT&T Comments and Reply Comments, *Promoting Interoperability in the 700 MHz Commercial Spectrum*, WT Docket No. 12-69 (June 1, 2012 and July 16, 2012); Comments of AT&T Inc., *Petition for Rulemaking Regarding Exclusivity Arrangements Between Commercial Wireless Carriers and Handset Manufacturers*, RM-11497 (Feb. 2, 2009).

foreclosure and thus were subject to no further scrutiny.[30] But in two recent transactions the Commission, out of the blue, began scrutinizing even spectrum aggregations that did not trip the screen.[31]

The Commission has provided virtually no analytical justification for this shift. It did not provide a detailed analysis of why the safe harbor policy that had been in place for the previous ten years was not working or should be replaced going forward, nor does the record in this proceeding provide any such analysis. As noted above and in AT&T's Comments, the one-third threshold that is currently used is, if anything, too conservative as there is no conceivable basis upon which a carrier with less than one-third of the spectrum that is suitable and available for the provision of wireless services in any market could foreclose competition. Therefore, subjecting such below-screen holdings to regulatory review is wholly unnecessary. Such review is also enormously harmful because it greatly increases the opportunity for regulatory rent seeking—the pursuit of a regulatory agenda that has nothing to do with spectrum foreclosure. One need look no further than the comments in this proceeding, which include proposals for spectrum

---

[30] Memorandum Opinion and Order, *Applications of AT&T Wireless Services, Inc. and Cingular Wireless Corporation for Consent to Transfer Control of Licenses and Authorizations*, 19 FCC Rcd. 21522, ¶ 109 (rel. Oct. 26, 2004) ("*AT&T-Cingular Merger Order*") ("[T]he function of [this initial screen] was simply to eliminate from further consideration any market in which there is no potential for competitive harm as result of this transaction …."); Verizon Wireless Comments at 8 n.15 (collecting citations); T-Mobile Comments at 5-6 (acknowledging that the screen is meant to be a safe harbor). As Verizon notes, the Commission's suggestion in the *Notice* that it "does not … limit its consideration of potential competitive harms in proposed transactions solely to markets identified by its initial screen" is actually belied by the cases it cites for that proposition. *See* Verizon Wireless Comments at 8-9 (demonstrating that the cases cited either reaffirm the screen as a safe harbor or focus on mergers where the further inquiry did not relate to spectrum aggregation *per se*).

[31] *See* Memorandum Opinion and Order, *Application of Cellco Partnership d/b/a Verizon Wireless and SpectrumCo LLC and Cox TMI, LLC for Consent to Assign AWS-1 Licenses*, 27 FCC Rcd. 10698, ¶ 74 (rel. Aug. 23, 2012); Order, *Application of AT&T Inc. and Qualcomm Incorporated for Consent to Assign Licenses and Authorizations*, 26 FCC Rcd. 17589, ¶ 42 (rel. Dec. 22, 2011).

restrictions that could be traded for unrelated regulatory concessions, and for spectrum aggregation policies that conveniently constrain everyone but the proponents for a glimpse of the abuses that would attend such review. And even if those reviews ultimately resulted in unconditional approval of the transaction, the review process itself would result in delay and deny providers the regulatory certainty that the Commission has recognized time and again is important in promoting investment and business planning. As a result, review of below screen transactions threatens to chill efficiency-enhancing and competition-enhancing secondary market transactions, the encouragement of which the Commission has recognized should be a part of national spectrum policy.[32]

To remedy these problems, the Commission should restore the spectrum screen to its original function, the one it served for ten years without adverse effects—that of a true safe harbor. With a strong reaffirmation that the screen is a true safe harbor, providers can have the certainty that transactions that do not trip the screen will not face unexpected regulatory roadblocks when they are contemplating how best to obtain the capacity they need to serve their customers at a time of exploding broadband growth.[33]

The other way the Commission can bring greater predictability and transparency to its spectrum screen is by regularly updating the spectrum included within the screen through judicially reviewable rulemaking proceedings. Again, there is broad support in the record for such processes. AT&T believes a particularly efficient approach would be for the Commission

---

[32] Federal Communications Commission, *Connecting America: The National Broadband Plan*, at 76-78, 83 (2010) ("*National Broadband Plan*").

[33] Katz-Israel Decl. ¶¶ 54-56; *see also, e.g.*, Verizon Wireless Comments at 10 ("This safe harbor is an essential element of an efficient and effective screen, because it allows the Commission to capture some of the benefits of a bright line rule while retaining the flexibility to conduct a meaningful review of transactions that exceed the screen and could raise competitive issues.").

to initiate such proceedings in conjunction with the Commission's annual report on the state of wireless competition.[34] That would reduce duplicative fact-gathering and help ensure that the proceedings were conducted on a timely and regular basis.

C. The Commission Should Make Appropriate Adjustments to the Spectrum Included in the Screen, Including Counting the BRS/EBS Spectrum that is Already Being Used for the Provision of Mobile Broadband Services.

There is widespread agreement that all spectrum that is currently suitable and available for mobile wireless services or likely to be so in the near future should be included in the screen. For example, many commenters agree that, applying this standard, the Commission should now modify the screen to include the 10 MHz of PCS G Block spectrum that Sprint is using for LTE services.[35] Similarly, the Commission has now conclusively settled that 40 MHz of MSS/ATC spectrum that is owned by Dish and 20 MHz of WCS spectrum is "useable" for mobile wireless services.[36]

Most importantly, however, the Commission must now include all BRS spectrum and at least 95 percent of EBS spectrum, rather than the mere 55 MHz of BRS spectrum that is included

---

[34] AT&T Comments at 44-45.

[35] *See, e.g.*, AT&T Comments at 42-43; Mobile Future Comments at 7-11; RTG Comments at 5-6; Verizon Wireless Comments at 19-22.

[36] In its recent *AWS-4 Report and Order*, the Commission "remove[d] regulatory barriers to mobile broadband use of the spectrum" and "adopt[ed] service, technical and license rules that will encourage innovation and investment in mobile broadband and provide certainty and a stable regulatory regime in which broadband deployment can rapidly occur." Report and Order and Order of Proposed Modification, *Service Rules for Advanced Wireless Services in the 2000-2020 MHz and 2180-2200 MHz Bands*, WT Docket No. 12-70, FCC 12-151, ¶ 1 (Dec. 17, 2012) ("*AWS-4 Report and Order*"). In its *WCS Spectrum Order* the Commission found that "20 MHz of WCS spectrum … are suitable and available for the provision of mobile telephony/broadband services and should therefore be added to the spectrum screen." Memorandum Opinion and Order, *Application of AT&T Mobility Spectrum LLC, New Cingular Wireless PCS, LLC, Comcast Corporation, Horizon Wi-Com, LLC, NextWave Wireless, Inc., and San Diego Gas and Electric Company For Consent to Assign and Transfer Licenses*, WT Docket No. 12-240, FCC 12-156, ¶ 31 (rel. Dec. 18, 2012) ("*WCS Spectrum Order*").

today. Although Sprint and Clearwire weakly maintain that the characteristics of this spectrum that led the Commission to exclude it from the screen "remain unchanged,"[37] those arguments lack any credibility. They are flatly inconsistent with those carriers' pronouncements everywhere but in regulatory proceedings at this Commission, and they cannot be reconciled with the undeniable reality that the spectrum they want to exclude from the screen is *today* being used for mobile broadband services. Notably, the Commission itself has recognized as much: in its most recent Wireless Competition Report, it explicitly counted 187 MHz of BRS/EBS spectrum as available for mobile use.[38]

The arguments by Clearwire and Sprint with regard to Clearwire's 2.5 GHz spectrum are particularly audacious given repeated public boasting by these companies of their unique and advantageous spectrum positions. Just last February, Clearwire boasted to Wall Street of its "deep . . . holdings" of BRS spectrum which makes it "better positioned to meet . . . increasing demand than any other carrier."[39] And a few weeks ago, Sprint announced that it intends to buy the minority interest in Clearwire it does not already hold in order "to maximize the value of Clearwire's 2.5 GHz spectrum and use it to increase Sprint's network capacity."[40] According to Sprint, the transaction will allow it "to use Clearwire's 2.5 GHz spectrum more effectively"

[37] *See* Clearwire Comments at 5-6; Sprint Comments at 8 n.14 & 13 n.26 (arguing that Commission has "thoroughly reviewed this issue on prior occasions").

[38] *Fifteenth Wireless Competition Report* ¶ 276 (Table 26); *see also* Fourteenth Report, *Implementation of Section 6002(b) of the Omnibus Budget Reconciliation Act of 1993*, 25 FCC Rcd. 11407, ¶ 259 (Table 24) (rel. May 20, 2010) ("*Fourteenth Wireless Competition Report*").

[39] Erik Prusch, President and CEO, Letter to Shareholders, at 2 (attached to 2011 Clearwire Annual Report (Feb. 16, 2012)) available at http://corporate.clearwire.com/annuals.cfm.

[40] Communications Daily at 8.

because the "value and utility" of that spectrum is enhanced by "combining it with Sprint's complementary core coverage at 1.9 GHz."[41]

These claims are flatly inconsistent with the notion that only a small fraction of this spectrum is suitable and available for mobile wireless use. In fact, in advancing their arguments, Sprint and Clearwire simply recycle arguments they made years ago when the Commission made the initial decision not to include this spectrum in the screen. As shown below, those arguments long ago lost whatever validity they may once have had.

For example, Clearwire argues that the 42 MHz of Middle Band spectrum is used for "high-site, high powered video service in some areas of the country, which can be incompatible with low-powered broadband operations."[42] As AT&T previously showed, although certain BRS spectrum *can* be used for high-powered operations, that fact does not distinguish it from other spectrum that is included in the screen.[43] Cellular and PCS can be used for fixed services, and lower 700 MHz C, D, and E Block spectrum can be used for high powered broadcasts, yet all of these bands are included in the screen as suitable and available because they can be used for mobile wireless services. There is no justification for excluding any segment of BRS/EBS spectrum simply because high power operations are also authorized; otherwise, the Commission would have to exclude all mobile spectrum permitting flexible use. Equally important, Clearwire itself holds all or nearly all of this spectrum in many markets and thus faces no threat of

[41] Sprint Nextel Corporation and Softbank Corp. Amendment, *In the Matter of Applications of Sprint Nextel Corporation, Transferor, and Softbank Corp., and Starburst II, Inc., Transferees, for Consent to Transfer of Control of Licenses and Authorizations*, IB Docket No. 12-343, at 6 (Dec. 20, 2012).

[42] Clearwire Comments at 6.

[43] AT&T Comments at 39-40.

interference.[44] There are very few licensees using any Middle Band spectrum to operate high-powered video services—indeed, AT&T's review of the Commission's publicly available BRS/EBS license records suggests that there are fewer than 100 sites nationwide where licensees answered "yes" to the question "Will the requested facilities be used to provide multichannel video programming service"—and such a small and isolated possibility of interference no longer justifies the wholesale exclusion of this spectrum.[45]

Clearwire also claims that all 6 MHz of BRS Channel 1 should remain excluded, because it must share 4 MHz with co-primary mobile satellite services ("MSS"), broadcast auxiliary service, and fixed microwave licensees.[46] Contrary to what Clearwire implies, however, the Commission did not exclude this spectrum on the basis that it was shared spectrum. Indeed, the Commission had already specifically held that mobile services could co-exist with these other uses.[47] Rather, the Commission excluded the spectrum "at this time" because it seemed unlikely that Sprint/Clearwire would use such spectrum for WiMAX services and because the spectrum

---

[44] Indeed, as AT&T previously noted, Clearwire has full access in many markets to all 194 MHz of BRS/EBS spectrum for 4G services, including EBS, BRS-1, MBS, and the 4 MHz Guard Bands that the Commission has previously excluded from the screen.

[45] *See, e.g.*, Verizon Wireless Comments at 26 ("Now, with years of experience under the new band plan, it is apparent that only a relatively few high-powered video systems remain in the Middle Band Segment. Thus, the diminished threat of interference no longer justifies a broad assumption that the Middle Band Segment should not be included in the screen.").

[46] Clearwire Comments at 6.

[47] *Sprint Nextel-Clearwire Order* ¶ 68; Report and Order and Further Notice of Proposed Rulemaking, *Amendment of Parts 1, 21, 73, 74 and 101 of the Commission's Rules to Facilitate the Provision of Fixed and Mobile Broadband Access, Educational and Other Advanced Services in the 2150-2162 and 2500-2690 MHz Bands*, 19 FCC Rcd 14165, ¶¶ 27-28 (rel. July 29, 2004) ("*BRS Report and Order*"). In reality, it is the satellite and other providers that must worry about interference from Clearwire, and the Commission has already held that as co-primary users they cannot claim interference protection from Clearwire's BRS operations. *Id.* ¶ 27 n.67.

band was not contiguous to other BRS channels.[48] Such concerns are no longer valid, because Clearwire *does* use that spectrum to provide WiMAX service today.[49]

Similarly, Clearwire's contention that the Commission should continue to exclude the J and K guard bands is meritless. Although such spectrum may be "assigned in small increments" to "secondary operations" as Clearwire states, neither of those conditions prevents Clearwire from using the spectrum to provide mobile wireless services. As Verizon notes, with the diminishing number of high-powered video operations in the Middle Band, "commercial operators can combine these narrow channels to provide mobile telephony/broadband," and therefore such spectrum should be included.[50]

Clearwire and Sprint argue that EBS spectrum should not be counted because Clearwire only leases the capacity from the license holders.[51] But the Commission attributes cellular, SMR, PCS, and 700 MHz spectrum to parties that lease it, and there is no reason why it should not count Clearwire's leased spectrum as well.[52] Leased spectrum is just as "suitable" and "available" for mobile services as other spectrum.[53] Indeed, as AT&T previously noted,

---

[48] *Sprint Nextel-Clearwire Order* ¶ 68.

[49] *See* Letter from Cathleen A. Massey, Vice President, Regulatory Affairs and Public Policy, Clearwire Corp., to Marlene H. Dortch, FCC Secretary, WT Docket No. 03-66, RM-11614, Attachment at 3, 4 (filed Oct. 19, 2012) ("[Clearwire] currently operates WiMAX and pre-WiMAX technologies in the 2496-2500 MHz band").

[50] Verizon Wireless Comments at 26-27.

[51] Clearwire Comments at 6.

[52] Second Report and Order, Order on Reconsideration, and Second Further Notice of Proposed Rulemaking, *Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets*, 19 FCC Rcd. 17507, ¶ 25 n.62 (rel. Sept. 2, 2004).

[53] *See, e.g.*, Verizon Wireless Comments at 24 ("when the Commission extended its secondary markets leasing policy to BRS/EBS spectrum, it explained that doing so would allow for 'more efficient and dynamic use of the important spectrum resource to the ultimate benefit of consumers throughout the country'") (quoting *BRS Report and Order* ¶ 179).

Clearwire's long-term leases of EBS spectrum provide much longer access to this spectrum than typical leases, which are limited by the underlying license term.[54]

Clearwire also repeats its argument that EBS spectrum is subject to a mandatory capacity reservation for educational uses.[55] A mandatory 5 percent hold-back certainly provides no reason to exclude the entire 100 percent of this spectrum from the screen; there is no question that at least 95 percent of this capacity is "suitable" and "available" for mobile services. Although there is no compelling reason to exclude any aspect of this spectrum, AT&T has no objection to inclusion of 95 percent of the spectrum in the screen, as Verizon suggests.[56] Accordingly, the Commission should include at least 111.625 MHz of EBS spectrum in the screen (95 percent of the full 117.5 MHz).[57]

Clearwire and Sprint both cite the Commission's previous conclusion that EBS licenses are site-specific and therefore have "white spaces" justifying continued exclusion from the screen.[58] As AT&T has explained, the Commission includes other types of spectrum that are also site-based and thus have "white spaces" gaps, most notably Cellular spectrum.[59] Here again, Sprint and Clearwire are asking for a blatant double standard that can no longer be

---

[54] *Compare* Description of the Transaction and Public Interest Statement, *In the Matter of Sprint Nextel Corporation and Clearwire Corporation Applications for Consent to Transfer Control of Licenses, Leases, and Authorizations*, WT Docket No. 08-94, at 40-41 (June 24, 2008) ("Sprint-Clearwire Public Interest Statement").

[55] *Sprint Nextel-Clearwire Order* ¶ 71.

[56] *See* Verizon Wireless Comments at 24-25 ("[w]ith the exception of five percent of EBS spectrum reserved for educational use, none of the EBS spectrum is 'committed to another use' and, in light of commercial providers' significant use of the EBS spectrum, the Commission should include the 95 percent of EBS spectrum available for commercial mobile use in the screen").

[57] *See id.* at 25 (table tabulating 95 percent of the various bands of EBS spectrum).

[58] Clearwire Comments at 6-7; Sprint Comments at 8 n.14; *Sprint Nextel-Clearwire Order* ¶ 71.

[59] FCC, *FCC Encyclopedia: Cellular Service* (Feb. 13, 2012), http://www.fcc.gov/encyclopedia/cellular-service.

lawfully maintained. But in all events, Sprint and Clearwire overstate the extent to which these gaps pose a problem. The density of EBS licenses is very high, particularly in populated areas, and since Sprint/Clearwire holds both BRS and EBS spectrum, it already has complete coverage through its BRS spectrum and thus even deeper coverage from EBS in the populated areas where deeper coverage can make a difference. Moreover, to the extent it believes that EBS white spaces make the band unusable in some areas, Sprint can make such a showing in individual cases; there is no justification for excluding the spectrum altogether.

Finally, calls for the Commission to remove a portion of SMR spectrum from the screen are premature.[60] Although only 14 MHz of the 26.5 MHz of SMR may be suitable for mobile broadband services, the remaining 12.5 MHz can be and is used today to provide mobile voice services, which frees up other spectrum to be used to provide data services. To be sure, there may come a day when carriers transition fully to LTE such that all voice service becomes part of a broadband data service, but that day has not yet arrived. Almost all carriers continue to operate legacy networks and require spectrum to handle the voice portion of their service, and as long as that remains the case, the Commission should continue to include the full 26.5 MHz of SMR spectrum in the screen.

II. PROPOSALS TO ADOPT SCREENS THAT WOULD GIVE GREATER WEIGHT TO SPECTRUM BELOW 1 GHz SHOULD BE REJECTED.

Although there is broad support for retaining the Commission's existing safe harbor approach, several commenters contend that the Commission's screen must reflect the purported "superiority" of "low frequency" spectrum relative to "high frequency" spectrum.[61] These

---

[60] CCA Comments at 14; Computer & Communication Industry Association ("CCIA") Comments at 9-10.

[61] *See* CCA Comments at 11-12; CCIA Comments at 11-17; Peha Comments at 4-5; RTG Comments at 9; Sprint Comments at 11-12; T-Mobile Comments at 14-16.

commenters contend that treating all spectrum equally is inappropriate because low frequency spectrum has superior propagation properties and mobile wireless networks can thus be deployed more cheaply on low frequency spectrum than high frequency spectrum. Based entirely on this premise, these commenters ask for a variety of regulatory changes, such as a screen that purports to "weigh" spectrum holdings according to either their market value[62] or a complex mathematical formula estimating deployment costs,[63] or to adopt an independent and parallel screen for all spectrum with a frequency below 1 GHz.[64]

There is *no* basis for any of these proposals because there is no link between spectrum frequency and the ability to undertake an anticompetitive foreclosure strategy. To the extent that low band spectrum allows a carrier to build out wireless networks in certain areas for lower cost, that difference will be reflected in the prices carriers pay for spectrum—spectrum that requires more capital investment in mobile network facilities will sell for less.[65] Accordingly, differences in deployment costs, like differences in other isolated characteristics of spectrum, do not in and of themselves confer any inherent competitive advantage, much less one that can or should be reflected in the spectrum screen. In all events, as described in the accompanying Report of Professors Jeffrey Reed and Nishith Tripathi, in many scenarios low band spectrum is not inherently superior to high band spectrum and, in high demand urban settings where spectrum scarcity is greatest, low band spectrum can have disadvantages relative to high band spectrum.[66]

---

[62] Sprint Comments at 11-12; *see also* CCIA Comments at 16.

[63] Peha Comments at 5.

[64] CCA Comments at 11-12; CCIA Comments at 10-17; RTG Comments at 9; T-Mobile Comments at 14-16. Sprint goes even further, arguing that the Commission should set a hard cap on sub-1 GHz spectrum. Sprint Comments at 10, 13. Adopting a sub 1-GHz cap would only exacerbate the flaws discussed below with regard to the proposed sub-1 GHz screen.

[65] Katz-Israel Reply Decl. ¶¶ 9, 22-24; Katz-Israel Decl. ¶¶ 91-92.

[66] Reed-Tripathi Paper at 8-10.

It should thus come as no surprise that the only commenter to attempt a serious analysis in support of a "weighted" approach actually undermines the basis for that approach by confirming these key points. Indeed, Professor Jon Peha concludes that low and high band spectrum should be given the same weight in areas where cell sizes are relatively small because of the level of demand—*i.e.*, the urban and high demand suburban areas where most mobile broadband use occurs.

Given the complete lack of foundation for weighting spectrum differently in the screen, it is clear that the real motivation behind these proposals is to (1) ensure the availability of low-band spectrum at below-market prices going forward by reducing competition for that spectrum; and (2) limit the ability of AT&T and other carriers that hold more low band spectrum to acquire the spectrum they need to serve their customers and compete aggressively in the marketplace. In other words, the carriers sponsoring these proposals want to pay less for the spectrum they buy and worry less about competition from their rivals. Although shielding less efficient carriers from market forces may be good for those companies' shareholders, adopting such proposals will invariably harm consumers and the economy.

A. The Proposed Weighting Schemes Are Fundamentally Flawed Both as a Matter of Economics and as a Matter of Wireless Engineering.

Regardless of their specifics, all of the proposed schemes to "weight" the spectrum screen or otherwise distinguish between spectrum bands are based on the premise that low band spectrum is inherently superior to high band spectrum. Specifically, proponents claim that it is cheaper to build a network to achieve the same level of capacity using low band spectrum than high band spectrum because the superior propagation properties of low band spectrum allow a carrier to construct fewer cell sites or otherwise deploy mobile networks at lower costs.[67] These assertions suffer from two independent and fundamental errors.

First, proponents of weighting the spectrum screen fail to account for the fact that the cost of providing retail wireless services includes both the cost of deploying cell networks *and* the cost of the spectrum itself.[68] Thus, as Professor Katz and Dr. Israel explained, "to the extent that high-frequency spectrum necessitates greater additional cost to achieve a certain degree of capacity expansion, all else equal, the price of the spectrum is expected to be lower, thus offsetting the higher cost."[69] Indeed, Professor Peha's own results indicate that price of spectrum decreases as the costs of deploying wireless networks using that spectrum increase.[70] Entities holding high band spectrum are thus not competitively disadvantaged and changes to the screen to reflect these non-existent disadvantages have no basis. For example, spectrum weightings based on market price would effectively force low-band providers to pay twice: they would first have to pay a marketplace premium reflecting any coverage-related cost savings and they would then have to pay again in the Commission's screening process, because the premium they already paid would effectively raise the cost (or eliminate the possibility) of future spectrum acquisitions as well.[71]

---

[67] *See, e.g.*, CCIA Comments at 14-15; Peha Comments at 6-15; T-Mobile Comments at 15.

[68] Katz-Israel Reply Decl. ¶¶ 9, 22-24; Katz-Israel Decl. ¶¶ 91-92.

[69] Katz-Israel Reply Decl. ¶ 22; *see also* Katz-Israel Decl. ¶ 92 ("In equilibrium, license prices will tend to equalize the total amount needed to purchase a license and make the associated investment in infrastructure to achieve a given capacity, so that—all else equal—a license that requires more capital investment will sell for less.").

[70] Katz-Israel Reply Decl. ¶ 25 (discussing Peha Comments at 13-14 & Figure 5); *see also* Reed-Tripathi Paper at 2, 12-13.

[71] Katz-Israel Reply Decl. ¶ 24; Katz-Israel Decl. ¶¶ 91-92.

Second, advocates of spectrum screen weighting are also wrong in their claim that low band spectrum is inherently better than high band spectrum. Numerous factors determine the value of any spectrum and those factors can vary among carriers and across different geographic regions.[72] For example, greater "amounts" of high band spectrum are available making it easier for a carrier to gain efficiencies by securing contiguous blocks of spectrum.[73] In addition, a carrier that already has deployed networks using high band spectrum will often prefer to acquire more spectrum at that frequency rather than operate using a second, low band frequency—and, indeed, T-Mobile made that very decision earlier this year when it chose to acquire high-band spectrum from Verizon instead of 700 MHz spectrum.[74] Providers also will often prefer high-band spectrum in urban areas where cell sites tend to be smaller to help minimize inter-cell interference and to achieve the maximum benefits of technologies, such as MIMO, that enhance throughput and capacity.[75] Further, the Commission's buildout requirements affect the value of spectrum; the buildout requirements for much high band spectrum typically require coverage of only small population centers over many years, whereas the requirements for 700 MHz spectrum, for example, require build to 35 percent of geographic areas in just a few short years (and later 70 percent).[76]

---

[72] Reed-Tripathi Paper at 5-8.

[73] *Id.* at 7.

[74] *Id.*; *see, e.g.*, Deutsche Telekom AG and MetroPCS Communications Inc., Description of Transaction, Public Interest Showing, and Related Demonstrations, *Applications of Deutsche Telekom AG, T-Mobile USA, Inc., and MetroPCS Communications, Inc. for Consent to Transfer Control of Licenses and Authorizations*, WT Docket No. 12-301, at iv (Oct. 18, 2012) ("T-Mobile-Metro PCS Public Interest Statement").

[75] Reed-Tripathi Paper at 7-8, 10-11.

[76] *See, e.g.*, 47 C.F.R. § 27.14; *Cf.* Reed-Tripathi Paper at 7.

In fact, as Professors Reed and Tripathi explain, due to these and other factors, low band spectrum can be relatively *less* desirable than high band spectrum in urban areas.[77] For example, although "inter-cell interference can be a problem for both low-band and high-band deployments, . . . it is a more challenging issue for low-band deployments because . . . low-band spectrum typically propagates further than high-band spectrum." As a result, "it can sometimes be more costly to minimize inter-cell interference for low-band networks than for high-band networks in dense urban areas, and it can be infeasible to avoid such interference completely when using low band spectrum."[78] Likewise, in urban areas, the performance of MIMO systems—which permit greater throughput and capacity—"would generally be better at a higher band than at a lower band."[79]

B. Each of the Three Proposed Weighting Schemes Suffer From Additional Flaws That Preclude It From Being Adopted.

In addition to the overarching flaws described above, each of the three proposed weighting schemes is flawed on its own terms.

Professor Peha's Weighting Analysis. Although Professor Peha advocates a weighting scheme, his own analysis finds that it should apply only outside the densely populated urban and suburban areas where most wireless consumers live. It would be patently arbitrary to impose a

---

[77] Reed-Tripathi Paper at 9-11. CCIA recognizes that high frequency spectrum is inherently superior for such "densification" but contends that carriers can obtain the same benefits using low frequency spectrum by making certain "technical adjustments." CCIA Comments at 14. In fact, as Professors Reed and Tripathi explain, one of the most significant difficulties with using low-band spectrum for densification is that the larger propagation range for low band spectrum results in inter-cell interference that often cannot be fully addressed and, where it can be addressed, requires significant engineering efforts. Reed-Tripathi Paper at 10.

[78] Reed-Tripathi Paper at 10.

[79] *Id*.

nationwide spectrum-weighting scheme based only on what Professor Peha concedes are the unusual circumstances of relatively rural areas.[80]

Moreover, although Professor Peha attempts to provide a rigorous methodology for measuring "the actual value of a spectrum band in facilitating low-cost infrastructure," he effectively concedes that it is not possible.[81] As he acknowledges, there are simply "too many factors to consider explicitly."[82] For example, a rigorous analysis would require consideration of the "frequency and bandwidth" of the spectrum, "how the band is fragmented in frequency and geography," "what equipment is available in the band," and "the technical and business strategy of every carrier in the market." And these factors "can change rapidly."[83]

Thus, Professor Peha only sought to undertake a "simplif[ied]" analysis that ignores many of the relevant "factors"—but even here he acknowledges that significant "further work" is required.[84] For example, Professor Peha's simplified modeling suggests that different weights be given to spectrum in "urban," "suburban" and "rural" areas, but he admits that multiple screens would be "confus[ing]" and offers no metric for how any actual regulation in practice would distinguish between such regions.[85] He also concedes that developing a weighting function

---

[80] Peha Comments at 6-9.

[81] *Id.* at 5-6.

[82] *Id.* In this regard, notwithstanding his statement that is an "unhealthy fallacy" to contend that "spectrum equals capacity," *id.* at 3, Professor Peha does not actually argue that high and low band spectrum have different data carrying capacity. *Cf.* Reed-Tripathi Paper at 3-5 (demonstrating that "from a wireless engineering standpoint in that the overall data-carrying capacity of spectrum used in cellular networks is essentially the same for all spectrum bands, including spectrum that is below and above 1-GHz"). Instead, Professor Peha seeks only to prove the costs of deploying cell networks to achieve a particular level of capacity in a geographic area can depend on the frequency. Peha Comments at 3-4.

[83] *Id.* at 6.

[84] *Id.* at 6, 11.

[85] *Id.* at 12.

would require "consideration of frequency bands above 1500 MHz"—in other words, the AWS, PCS, WCS, and BRS/EBS spectrum that would be critical to any actual rule—but he throws up his hands and says that was "beyond the scope" of his paper.[86]

To the extent that any reliance can be placed on such tentative and incomplete analysis, Professor Peha's results undermine the case for adopting a weighted spectrum screen. Specifically, Professor Peha determined that population density was the most important determinant for network deployment costs and purported to calculate how spectrum frequency can affect infrastructure cost in three scenarios: urban, suburban, and rural areas.[87] For urban areas, however, Professor Peha found that cell size, and hence the cost of deploying mobile networks, is *not* materially impacted by the propagation characteristics of spectrum.[88] That is because, in relatively high demand areas, the size of a cell is sufficiently small that even the "highest frequency" spectrum can be used to provide complete coverage for the cell.[89]

Thus, Professor Peha concludes that in these circumstances "the value of a MHz-POP . . . should be roughly the same in all frequency bands."[90] The urban and other high demand areas where Professor Peha concludes there should be no weighting represent the majority of the population and are the areas where the need for spectrum is the greatest.[91] In contrast, outside of top urban markets, "spectrum is not a sufficiently scarce resource to serve as a basis for

---

[86] *Id.* at 11.

[87] *Id*. at 6-11.

[88] *Id.* at 9.

[89] *Id.*; *see also* Reed-Tripathi Paper at 10. Sprint likewise acknowledges that high frequency spectrum "is well-suited to maximizing cellular reuse and thereby increasing subscriber capacity while maintaining broadband speeds in densely populated markets." Sprint Comments at 7-8.

[90] Peha Comments at 9.

[91] Reed-Tripathi Paper at 8-11.

foreclosure."[92] As Professor Katz and Dr. Israel show, the price for spectrum in rural areas is much lower than urban areas.[93] And to the extent that demand in a rural market increases substantially, those markets will begin to resemble more urban markets that Peha himself recognizes raise no competitive issues—*i.e.*, cell sizes will decrease such that full coverage can be provided using high band spectrum.[94]

Further, as explained in greater detail by Professors Reed and Tripathi, Professor Peha's findings regarding the costs of deploying mobile networks in rural and suburban areas cannot be credited because Professor Peha relied on unjustified assumptions that vastly overstate the relative "disadvantages" of using high band spectrum.[95] With regard to rural deployment, Professor Peha assumes a base case in which each low band cell site would cover an area larger than Connecticut.[96] Because of the earth's curvature, such distances cannot be achieved by cell towers that comply with zoning restrictions and that can be feasibly constructed—indeed, the tower would need to be taller than the Empire State Building.[97] In any event, in real-world deployments, quality of service standards dictate much, much smaller cell sizes than Professor Peha assumes.[98]

[92] Katz-Israel Reply Decl. ¶ 9; *see also id.* ¶ 20 ("[I]n rural areas, spectrum is not the type of scarce resource likely to give rise to foreclosure concerns.").

[93] *Id.* ¶ 20 & Figures 4-A, 4-B.

[94] *Id.* ¶ 21.

[95] Reed-Tripathi Paper at 11-18.

[96] *Compare* Peha Comments at 7 *with* Reed-Tripathi Paper at 13-14.

[97] Reed-Tripathi Paper at 13-14.

[98] *Id.* at 14.

Professor Peha's rural scenario cost calculations also assume "greenfield" deployment.[99] In the real world, however, providers have already deployed mobile service in most areas where people live.[100] By incorrectly assuming that providers deploying new spectrum will be required to bear the entire cost of building and operating all of the cell sites needed to support that deployment, Professor Peha greatly overstates the relative costs of deploying service with low and high band spectrum.[101]

In suburban areas, Professor Peha assumes that a carrier will want to use low band spectrum for coverage and high band spectrum for "capacity."[102] Although theoretically possible, that is not how real-world networks are engineered.[103] Such an approach is inefficient because it requires a network provider to constantly hand-off traffic between high and low frequency bands within the same cell.[104] This consumes substantial resources, reducing overall network capacity.[105] That is why when AT&T uses both low and high band spectrum in the same area, its design goal is ultimately to have complete coverage over the cell with both bands.[106] Professor Peha then compounds this error by misapplying standard engineering formulae in a way that further exaggerates the differences in capacity and throughput for low and high band networks.[107]

---

[99] Peha Comments at 7-8.

[100] Reed-Tripathi Paper at 6.

[101] *Id.* at 7.

[102] Peha Comments at 10; *see also* CCIA Comments at 15; Sprint Comments at 8.

[103] Reed-Tripathi Paper at 8.

[104] *Id.* at 8, 16-17.

[105] *Id.*

[106] *Id.* at 16-17.

[107] *Id.* at 11-19.

According to Figure 3 of his comments, Professor Peha graphs the value of spectrum as declining sharply in a straight line as the frequency increases, until 1500 MHz spectrum has almost no value.[108] Although Professor Peha (tellingly) provides no results above 1500 MHz, the clear implication of his analysis is that the continuing decline in value would leave large portions of AWS spectrum, and all of PCS, WCS and BRS/EBS spectrum, as having *negative* value in rural areas.[109] The Commission could not lawfully assign spectrum weights on the basis of such a patently flawed analysis.

"Market Value" Weighting. A market-value weighting regime is equally flawed. Apart from the fatal double counting problem noted earlier, it could not be feasibly implemented. Any regulatory attempt to divine the true market value of spectrum would be hopelessly complex and prone to error. As Professor Katz and Dr. Israel explained, the "price of a spectrum license reflects a wide variety of factors, including: the geographic scope of the license; the presence of incumbent users; projections of wireless demand and the possibility of future license auctions at the time of sale; public policy restrictions placed on the use of the spectrum; and spectrum propagation properties."[110] Proponents of spectrum weighting offer no explanation as to how price variations reflecting these factors are indicative of the relative competitive importance of the spectrum.

Ironically, Professor Peha's testimony underscores these concerns. He highlights that the value of a bid "depend[s] on many other things" beyond the "intrinsic value of the spectrum" such as "the level of pent-up demand for spectrum at the time of the auction, the number of carriers in a position to bid at the time of the auction, the interest rate at the time of the auction,

[108] Peha Comments at 9, Figure 3.

[109] Katz-Israel Reply Decl. ¶ 26 & Figure 5; Reed-Tripathi Paper at 13.

[110] Katz-Israel Decl. ¶ 89.

the general state of the economy and therefore cellular revenues at the time of the auction, the regulations imposed on the winner which can vary from band to band, the extent to which the band has already been cleared and the cost of clearing it, the extent to which that spectrum band is available internationally which can change over time, how adjacent bands are being used at the time of auction, and more."[111] With regard to secondary sales, he observes that such transactions "are relatively infrequent and the financial details are sufficiently opaque that this may produce an incomplete and perhaps distorted picture."[112]

Indeed, such variations can exist even within a spectrum band. For example, because of interference and regulatory issues, the price for 700 MHz spectrum with comparable propagation properties sold at Auction 73 varied from less than $0.25 per MHz POP to more than $2.50 per MHz POP.[113] Proponents of spectrum weighting offer no explanation as to how these price variations are indicative of the relative competitive importance of the spectrum or how to account for these variations in any weighting scheme.

Finally, as Professor Peha notes, "the value bidders were willing to pay at the time of the auction may be quite different from the value today,"[114] but the Commission does not have the expertise to determine accurately what price any given spectrum would currently fetch and to update those values going forward in today's dynamic marketplace.[115] Myriad factors significantly affect the relative value of different spectrum bands, and any Commission attempt to account for all factors that may impact spectrum values would be unworkable given the

[111] Peha Comments at 12-13.

[112] *Id.* at 13.

[113] Katz-Israel Decl. ¶ 89 & Figure 2.

[114] Peha Comments at 12.

[115] AT&T Comments at 67; Katz-Israel Decl. ¶ 93.

constantly evolving considerations that may impact the relative value of any given spectrum block to any given provider at any given place and time.[116] The Commission's recent *AWS-4 Report and Order* highlights these points. There, the Commission recently adopted service rules that "dramatically increas[e] the value" of the AWS-4 Band.[117] But because Dish had previously acquired the spectrum under different service rules, there is no ready "market" value for this spectrum.[118] And even if the Commission could accurately measure the value of spectrum today and account for all of the myriad factors affecting that value going forward, the process of "updating" the value of spectrum could lead to absurd results: A carrier that acquired no additional spectrum could suddenly find itself above the "screen" because of a supposed increase in the "market value" of its existing spectrum holdings.[119]

The purported "value weights" touted by Sprint starkly illustrate the shortcomings inherent in such an approach.[120] Sprint's proposed weighting scheme is based on the testimony of Professor Peter Cramton sponsored by T-Mobile in the Verizon-SpectrumCo proceeding (testimony T-Mobile does not itself cite and appears to no longer support). Professor Cramton conducted no meaningful analysis of market values but relied entirely on equity research reports

[116] *See* AT&T Comments at 67.

[117] *AWS-4 Report and Order* ¶ 5. At the same time, the service rules the Commission adopted required AWS-4 licensees to accept interference from the AWS Upper H Block. *Id.* ¶ 18. Such requirements could also affect the value of the AWS-4 (and AWS H Block) spectrum.

[118] *Id.* ¶ 14.

[119] AT&T Comments at 67.

[120] Sprint Comments at 12. Notably, while arguing that its proposed weights are a "reasonable starting point," Sprint acknowledges that "additional study" is necessary by the Commission and ultimately does not propose any particular weighting scheme. *See id.* at 13.

from J.P. Morgan and Deutsche Bank.[121] The J.P. Morgan report, however, appears largely to have plucked relative spectrum values from thin air.[122] The only two data points cited are the *average* prices paid in the 2006 AWS auction and the 2008 700 MHz auction.[123] From those figures, J.P. Morgan concludes that 700 MHz spectrum is worth nearly twice as much as AWS spectrum. But even apart from the fact that there were very large variations in the prices paid for particular blocks in each of those auctions, and even apart from the fact these stale data cannot be presumed to be reflective of current market values,[124] no apples-to-apples comparison of the averages is possible as there are many reasons why AWS spectrum may have been valued lower in 2006 (including the fact that AWS spectrum required significant clearing and that the 2006 auction preceded the iPhone-driven wireless data explosion that greatly increased the demand for and value of wireless spectrum).

The remaining J.P. Morgan valuations are simply *ad hoc* assertions unsupported by analysis or explanation: a "30% premium" is added to top 100 markets, cellular is deemed 25 percent more valuable than 700 MHz, AWS values were assumed to have increased 38 percent from 2006, and MMDS and 2.5 GHz are arbitrarily discounted 67 percent and 75 percent,

---

[121] *See* Petition to Deny of T-Mobile USA, Inc., *Application of Cellco Partnership d/b/a Verizon Wireless, SpectrumCo LLC, and Cox TMI Wireless, LLC For Consent to Assign Licenses*, Cramton Decl. ¶¶ 31-36 (Feb. 21, 2012) (filed in WT Docket No. 12-4).

[122] J.P. Morgan, *Spectrum Valuation Overview – Carrier by Carrier Base-Case Spectrum Value Across Wireless Industry, Telecom Services and Towers*, North America Equity Research (Nov. 30, 2011) ("2011 J.P. Morgan Report").

[123] *Id.* at 5-6.

[124] J.P. Morgan recently issued revised valuations that "estimate[s] AWS and PCS spectrum values are up 26% from the 2006 AWS auction average." J.P. Morgan, *Spectrum Overview and Valuation Matrix – Carrier by Carrier Spectrum Value Across the Wireless Industry, Telecom Services and Towers*, North America Equity Research, at 9 (Dec. 5, 2012). Although no meaningful weight can be given to JP Morgan's more recent analysis because it suffers from the same flaws as its prior analysis, these substantial changes in values underscore the flaws in any attempt to use a spectrum screen with market value weighting.

respectively, from the AWS value.[125] For its part, the Deutsche Bank report never even purports to identify relative spectrum valuations. Rather, the portion of the report relied on by Cramton merely lists prices paid for spectrum at Commission auctions since 2005 and expressly warns that the average auction values it lists "can be misleading."[126] This is the "reasonable starting point" that Sprint advocates for a developing a "more reliable, accurate and more useful method for evaluating the competitive implications of future spectrum acquisitions."[127]

Separate Sub-1 GHz Screen. The proposed sub-1 GHz screen is even more radical and arbitrary than schemes to assign relative weights to different spectrum bands because it effectively treats high band spectrum as competitively irrelevant.[128] Because there is no justification even for weighting sub-1 GHz spectrum relative to higher band spectrum, there certainly is no basis for subjecting it to its own unique screen that completely ignores other spectrum.

The premise of the proposed sub-1 GHz screen is that this spectrum is so uniquely valuable that other spectrum cannot serve as a competitive substitute. But marketplace evidence conclusively refutes this premise. In a substantial number of markets, AT&T and Verizon are using spectrum in excess of the proposed sub-1 GHz screen.[129] Yet proponents of that screen

---

[125] 2011 J.P. Morgan Report at 5.

[126] Deutsche Bank, *Key Updates on Major Spectrum Deals*, US Telecom Services, Market Research (Feb. 5, 2012).

[127] Sprint Comments at 12.

[128] Some commenters would go even further, suggesting that the Commission should consider adopting band-specific caps in the context of forthcoming auctions. CCIA Comments at 21. These proposals suffers from these same flaws noted above and additional ones. They would balkanize spectrum on a band-by-band basis preventing carriers from rationalizing spectrum holdings even where holdings were only a small fraction of overall available spectrum. In all events, as explained below, such restrictions would violate 47 U.S.C. § 309(j)(17)(A).

[129] *See* CCA Comments at 5; RTG Comments at 9; Sprint Comments at 5-6.

cannot identify a single instance in which that ownership has led to foreclosure. To the contrary, numerous competitors are deploying LTE and going toe-to-toe with Verizon and AT&T with little or no sub-1 GHz spectrum.[130]

That, of course, is hardly surprising because, as shown above, low band spectrum is not more suitable for the provision of mobile broadband services in the urban and suburban areas where competition is most intense and where spectrum resources are most scarce. Higher-band spectrum has its own advantages in those areas which can and do eclipse the advantages of lower-band spectrum for many carriers. And this is why T-Mobile publicly eschewed the opportunity to obtain 700 MHz spectrum from Verizon in favor of more AWS spectrum. It is why carriers like Clearwire continually tout their superior spectrum position despite relying entirely on higher-band spectrum. It is also why Softbank is purchasing Sprint, and why Sprint is now seeking to acquire 100 percent ownership of Clearwire.

Proposals for a separate low-band screen, like proposals to weight sub-1 GHz spectrum, should thus be seen for what they are, which is nothing more than pretense for limiting the ability of AT&T and Verizon to compete in the upcoming auction of broadcast spectrum. The proponents of these proposals chose not to bid in the 700 MHz auction or seek 700 MHz spectrum in secondary markets. They now want the Commission to guarantee them an easy path to a winning bid in the upcoming broadcast spectrum auction through rules that limit the ability of AT&T and Verizon to participate.

III. VARIOUS OTHER PROPOSED MODIFICATIONS TO THE SPECTRUM SCREEN ANALYSIS SHOULD BE REJECTED.

Various commenters propose other changes to the spectrum screen analysis. As discussed below, none of these proposals is well-considered.

---

[130] Katz-Israel Reply Decl. ¶¶ 49-54.

A. The Commission Should Reject T-Mobile's Self-Serving and Arbitrage-Friendly Proposal to Adopt a Cap for Auctions But Allow a Screen for Secondary Market Transactions.

Although T-Mobile believes the Commission should "retain[] its case-by-case analysis for evaluating secondary transactions," it urges the Commission to adopt "bright-line caps for the acquisition of spectrum through auctions."[131] Under this approach, "[e]ntities would be prohibited from acquiring spectrum through an auction where the additional spectrum would cause them to exceed the relevant limit," which T-Mobile would have set as "one-third of the spectrum available for mobile wireless services."[132] According to T-Mobile, this would "give applicants certainty as they plan for and participate in an auction."[133]

This proposal is incoherent. In endorsing the Commission's current approach for secondary market transactions, T-Mobile acknowledges that many above-screen acquisitions can serve the public interest by allowing spectrum to flow to its highest-valued use yet raise no risk of foreclosure.[134] But if it is appropriate for a carrier to acquire spectrum in excess of the screen in a secondary market transaction, it is no less appropriate if the carrier does so in an auction.[135] "The goal of aggregation policy should be to permit pro-competitive outcomes and prevent only those outcomes that create a real risk of foreclosure, regardless of the institutional form of the transaction."[136] To be sure, the Commission has an interest in ensuring that those who win

---

[131] T-Mobile Comments at 7; *see also* United States Cellular Corporation ("USCC") Comments at 7-8.

[132] *Id.* at 9. As noted above, T-Mobile also argues that a separate screen would apply to spectrum below 1 GHz, but that proposal has no support in either economics or wireless engineering principles.

[133] *Id.* at 8.

[134] T-Mobile Comments at 12-13.

[135] Katz-Israel Reply Decl. ¶¶ 55-63.

[136] *Id.* ¶ 56.

spectrum rights in an auction are eligible to receive the licenses they have won, and spectrum holdings acquired at auction that cause the winning carrier to exceed the threshold will trigger scrutiny. But that does not mean that those holdings will be deemed impermissible, and even if it did, the carrier may choose to retain the spectrum won at auction and bring its holdings within the threshold by divesting different spectrum. There is no reason it should not have the right to do that.

Indeed, as Professor Katz and Dr. Israel explain, "if anything, auctions for newly released spectrum should be subject to more lax restrictions on outcomes than other transactions."[137] By definition, an auction *increases* the amount of spectrum available to wireless providers without reducing the spectrum holdings of any provider. This can only be viewed as presumptively decreasing the likelihood of foreclosure.[138]

According to T-Mobile, auctions caps are a necessity because Commission review and potential divestitures can "delay the ultimate licensing of spectrum to entities that will use it to offer services to the public."[139] This is a makeweight argument. For one thing, there is nothing to prevent the winning bidder from proceeding expeditiously with any necessary divestitures, particularly since the divestiture process will not relieve it of any build-out requirements that come with the acquired spectrum. And since it generally takes several years post-auction for the necessary standards to be adopted for newly licensed spectrum and the necessary equipment to be developed, tested, and commercially deployed, it is unlikely that any necessary divestiture

---

[137] *Id.* ¶ 58.

[138] *Id.*

[139] T-Mobile Comments at 8-9; *see also* MetroPCS at 16; Sprint at 10.

process would affect the deployment schedule even if the divestitures could not be quickly effected.[140]

The proposal also would result in a large transfer of wealth from the U.S. Treasury to private entities. It would do so in two ways. First, by limiting participation by AT&T and Verizon in the forthcoming 600 MHz auction, the proposal could only be expected to drive down the price of the winning bids in that auction. With less competition for the spectrum, carriers that won spectrum licenses in that auction invariably pay less than they would have in the absence of this proposal. Second, the proposal would create arbitrage opportunities: the regime would create the incentive and ability for speculators to acquire spectrum at auction and then resell it to those who were barred from participating but who could put the spectrum to its best use and would thus be willing to pay more for the spectrum than did the winning bidder.[141] Since the proposal does not impose a cap on secondary market transactions, that transfer would be permitted, subject only to the case-by-case review process. If the provider that ultimately ended up with the spectrum had been permitted to participate in the auction in the first place, the profit margin earned by the speculator that flipped the spectrum would have gone to the U.S. Treasury.[142]

---

[140] Relatedly, T-Mobile's "claim that, whereas auction rules affect all bidders in an auction, Commission policy toward transactions affects only the parties themselves is nonsensical." Katz-Israel Reply Decl. ¶ 57 (citing T-Mobile Comments at 8). If multiple parties are potentially interested in a particular spectrum license, then they are all effected by the transfer of that spectrum, whether by auction or private secondary transaction. *Id.* More broadly, "the relevant question for spectrum aggregation policy is the effect on downstream-market competition, and a cap affects all firms in the industry and all consumers regardless of the institutional form of the transaction." *Id.*

[141] *Id.* ¶ 59.

[142] *Id.* ¶ 62. Indeed, the unlawful restriction on auction participation advanced by T-Mobile might prevent the 600 MHz auction from clearing, thus preventing that spectrum from being "suitable and available" for wireless mobile services.

Finally, and most importantly, because T-Mobile is proposing "auction-specific" caps that would preclude certain carriers from participating in the forthcoming auction in particular markets, T-Mobile's proposal would be unlawful.[143] In the recent Middle Class Tax Relief and Job Creation Act of 2012, P.L. 112-96 (Feb. 22, 2012), Congress authorized the Commission to establish incentive auctions for certain spectrum blocks currently held by TV broadcasters and other entities. But it also amended the Communications Act to limit the Commission's authority to limit participation in any system of competitive bidding employed by the Commission pursuant to section 309(j) of the Communications Act. Section 309(j)(17)(A) provides that, "[n]otwithstanding any other provision of law," the Commission "may not prevent a person from participating" in an auction, as long as the potential bidder (i) "complies with all auction procedures and other requirements to protect the auction process" and (ii) meets the relevant "technical, financial, character, and citizenship" requirements.

In subsection (A), Congress prohibits the Commission from adopting any auction-specific rules that would affect any bidder's ability to participate beyond the existing rules on financial, technical, and character suitability and the other basic rules related to management of the auction procedures. Courts have made clear that when Congress prevents an agency from engaging in an activity "notwithstanding any other provision of law," that statutory phrase is absolute.[144] This provision clearly forecloses the "auction-specific" rules suggested by T-Mobile that would affect the ability of AT&T and others to participate in Commission auctions.

[143] T-Mobile Comments at 7; *see also* CCIA Comments at 21.

[144] *See, e.g.*, *Multistate Communications, Inc. v. FCC*, 728 F.2d 1519, 1525 (D.C. Cir. 1984) ("the phrase, 'notwithstanding any other provision of law' overrides any prior, inconsistent provision of the Communications Act"); *Cisneros v. Alpine Ridge Group*, 508 U.S. 10, 18 (1993) ("As we have noted previously in construing statutes, the use of such a 'notwithstanding' clause clearly signals the drafter's intention that the provisions of the 'notwithstanding' section override

T-Mobile's proposal is not saved by Section 309(j)(17)(B), which preserves the Commission's authority "to adopt and enforce rules of general applicability, including rules concerning spectrum aggregation that promote competition," because T-Mobile is not proposing rules of general applicability. It is instead proposing exactly what subsection (A) forbids: rules that apply specifically and uniquely to auctions and that affect the ability of one or more carriers to participate in one or more auctions. The authority preserved by subsection (B) cannot be used as a backdoor mechanism for circumventing the restrictions on the Commission's authority in subsection (A). In this general rulemaking context, the Commission cannot prohibit licensees from participating in auctions; rather, its authority is limited to establishing spectrum aggregation limits, under which a successful bidder would be responsible, at the conclusion of an auction in which it acquired spectrum, for undertaking divestitures or otherwise bringing itself into compliance with the total spectrum aggregation limits.

B. Free Press's "Three-Stage Analytical Approach" Is Inconsistent With Sound Economics and Would Create Enormous Marketplace Uncertainty.

In addition to asking the Commission to impose a "hard cap," Free Press proposes that the Commission subject even below cap transactions to what it asserts is an "antitrust" review.[145] Specifically, Free Press says that the Commission should apply the HHI framework from the *Horizontal Merger Guidelines* to establish whether there should be "a presumption for or against" a below-cap spectrum transaction.[146] If a negative presumption is established, the Commission would undertake an open-ended inquiry of a variety of factors to determine whether

---

the conflicting provisions of any other section."); *Liberty Maritime Corp. v. United States,* 928 F.2d 413, 416 (D.C. Cir. 1991) ("a clearer statement is difficult to imagine").

[145] Free Press Comments at 12-19.

[146] *Id.* at 15-16.

the applicant could show, by "clear and convincing evidence," that the transaction would nonetheless "promote competition."[147]

Such an approach would turn antitrust policy on its head while subverting the Commission's goal of restoring predictability to spectrum aggregation policy.[148] The Department of Justice and the Federal Trade Commission do not apply the HHI screen to inputs—it is applied to firms' shares of sales in the context of an acquisition of a direct competitor.[149] In other words, the HHI screen is not used to limit expansion of a firm—indeed, the antitrust laws never condemn internal growth "as a consequence of a superior product [or] business acumen."[150] Thus, it is unsurprising that Free Press is unable to provide any analysis whatsoever as to why a particular change in "concentration" of spectrum inputs can be "presumed" to facilitate foreclosure—particularly where the large majority of spectrum would continue to be held by *other* carriers. Nor does Free Press come to grips with the obvious inapplicability of its regime in the auction context, where the supply of spectrum is being expanded. Indeed, in the auction context, there would be no way for the participants to know *ex ante* what the market "concentration" would be until *after* the results of the auction.[151]

Beyond that, it is hard to imagine a regime that would create greater uncertainty as to whether a spectrum transaction would be allowed—and a concomitant reduction in incentives to undertake spectrum transactions needed to expand existing offerings or develop new innovative services. Under Free Press's approach, *any* spectrum transaction of *any* level could be subject to

---

[147] *Id.* at 16.

[148] *See* Katz-Israel Reply Decl. ¶¶ 37-43.

[149] *See* Department of Justice/Federal Trade Commission, Horizontal Merger Guidelines, § 5 (Aug. 19, 2010); *see also* Katz-Israel Reply Decl. ¶ 41.

[150] *United States v. Grinnell*, 384 U.S. 563, 570-71 (1955).

[151] Katz-Israel Reply Decl. ¶ 43.

a wide-ranging inquiry into whether there is "clear and convincing evidence that the transfer would promote competition."[152] Even modest transactions that would leave a carrier well under the cap could be deemed presumptively anticompetitive under this approach.[153]

C. The Commission Should Not Engraft an "Efficiency" Analysis as an Adjunct to Its Existing Approach.

MetroPCS contends that the Commission should consider a carrier's need for the spectrum in considering whether to allow the carrier to acquire spectrum in excess of the safe harbor threshold.[154] To the extent that MetroPCS is arguing that incumbent carriers with "large and growing customer bases" should generally be able to acquire additional spectrum to continue to expand,[155] AT&T agrees. As Professor Katz and Dr. Israel explained, an increase in spectrum holdings can result "from a wireless provider's success in using existing spectrum rights to offer services that consumers find attractive relative to those of rival providers" and, as such, the increase "is a sign that consumers are *benefiting* by being able to take advantage of improved mobile service offerings."[156] Binding aggregation limits, however, can serve as a "success tax," raising the costs of efficient providers and reducing incentives to invest and innovate.[157]

But to the extent that MetroPCS is suggesting that a carrier must prove to the Commission's satisfaction that it is using its existing spectrum "efficiently,"[158] that suggestion

---

[152] Free Press Comments at 16.

[153] For example, the acquisition of seven percent available spectrum by a carrier with eight percent of existing spectrum would increase the HHI by 100. Katz-Israel Reply Decl. ¶ 42. In a "concentrated market," this would be deemed presumptively anticompetitive under Free Press' approach.

[154] MetroPCS Comments at 13.

[155] *Id.*

[156] Katz-Israel Decl. ¶ 22.

[157] *Id.* ¶ 23.

[158] MetroPCS Comments at 15.

should be rejected. Market forces, not central planners, should determine which carriers should hold which spectrum. Market forces give carriers strong incentives to deploy expensive spectrum efficiently—and will punish carriers that fail to do so.[159] In contrast, "[t]he Commission is not in position to determine whether a certain level of spectrum usage at a certain time is 'efficient' as opposed to other options."[160] Moreover, undertaking an "efficiency review" as part of a review of a spectrum transaction would almost certainly create a rent-seeking free-for-all in which competitors used the process to obtain sensitive business data and block pro-competitive transactions on the grounds that the acquiring party cannot prove that the acquiring carrier is using its existing spectrum "efficiently enough."[161] Any legitimate warehousing concerns are better addressed through build-out requirements rather than a Commission inquiry into the extent to which a carrier is using spectrum with sufficient efficiency.[162]

Relatedly, Professor Peha suggests in passing that the Commission should consider collecting and using the number of cell towers per square kilometer deployed by a carrier in each spectrum band to assess whether the carrier is "warehousing" spectrum. He states that "[i]f this number is considerably lower than can be seen from competitors in the same region or simply low considering other relevant factors, and the carrier is still trying to expand its spectrum holdings, then this could be an indicator that spectrum is being warehoused."[163] He admits, however, that such a statistic is only "[p]otentially useful" as a warehousing indicator.[164] As

---

[159] Katz-Israel Decl. ¶ 102.

[160] AT&T Comments at 74.

[161] *Id.*

[162] *Id.* at 77.

[163] Peha Comments at 15.

[164] *Id.*

Professors Reed and Tripathi explain, this metric is not even "potentially useful."[165] There are many legitimate reasons why a carrier may be using a smaller number of cell towers than competitors in the same area, *e.g.*, different providers may have different technologies, different performance targets, and different legacy networks with existing cell sites.[166] Moreover, the Commission already has build-out requirements designed specifically to prevent warehousing of spectrum.

D. The Commission Should Not Adopt a Separate National Screen.

Finally, a few commenters ask that the Commission adopt a parallel, "national" screen in addition to its existing "local" screen.[167] These commenters make no attempt to show how the proposal would help the Commission identify spectrum holdings that could be used to foreclose competition. Nor could they. Spectrum can only be used in its licensed areas and spectrum licensed in one area cannot be used to foreclose competition in another area.[168]

Indeed, as Professor Katz and Dr. Israel already explained, a national spectrum screen would serve no meaningful function apart from the existing local screen:

> Because no mobile wireless service provider can have spectrum holdings in more than 100 percent of the local markets, a nationwide screen would have no impact unless its threshold were set lower than the local screen's threshold. That is, unless the national screen were set lower than the local thresholds, a spectrum transaction could never cross a national threshold without also crossing at least some local thresholds (*i.e.*, in those areas where a party had particularly large spectrum holdings). If the local thresholds were set at an appropriate level, then there is no sound public-interest rationale for setting a lower nationwide threshold.[169]

---

[165] Reed-Tripathi Paper at 4, 18-19.

[166] *Id.* at 18-19.

[167] CCIA Comments at 19-20; CCA Comments at 13.

[168] AT&T Comments at 77.

[169] Katz-Israel Decl. ¶ 76.

A national screen would also distort incentives in ways that are clearly harmful to the public interest. It would, for example, punish a carrier with relatively "large" national holdings from entering new local markets, even where the carrier would be a new entrant with modest spectrum holdings.[170] Investment incentives would also be undermined by the uncertainty inherent in this screen. And because there are any number of metrics that could be used to accomplish the necessary weighted averaging, a proposed national screen would result only in additional controversy and regulatory uncertainty.[171]

IV. THE COMMISSION'S PROPOSED ATTRIBUTION RULES SHOULD APPLY PROSPECTIVELY TO FUTURE SPECTRUM ACQUISITIONS, NOT RETROACTIVELY TO EXISTING SPECTRUM HOLDINGS.

A. There Is No Support for the Proposed 10 Percent Attribution Threshold or Singling Out AT&T for Differential Treatment.

Although there was broad agreement that the Commission should codify its attribution rules to promote regulatory certainty, the comments confirm that the proposed standard of "attributing" "non-controlling interests of 10 percent or more in mobile spectrum holdings" is arbitrary and should not be adopted.[172] Any such attribution rules must be supported by a showing that a 10 percent level of minority ownership will allow the minority owner to influence the spectrum holder to warehouse its spectrum in order to foreclose competition.[173] The Commission cited no such evidence in the *Notice*,[174] nor have the commenters. Given that the

[170] *Id.* ¶ 78.

[171] AT&T Comments at 79.

[172] *See, e.g.*, CCIA Comments, at 23 (stating "the Commission has never fully explained the rationale behind a ten percent limit for spectrum attribution purposes"); Clearwire Comments at 7 (arguing that the current 10 percent rule discourages investment); MetroPCS Comments at 18 (noting that the current rule is "unduly limiting" and unlikely to indicate control).

[173] AT&T Comments at 81.

[174] *Id.* at 80-81.

Commission has previously found that a 20 percent ownership interest was an appropriate standard,[175] there is no non-arbitrary basis on this record for adopting the lower threshold.

The only party to endorse the proposed 10 percent attribution threshold is RTG. But the entirety of RTG's analysis is the assertion that "[a]ttributing non-controlling interests of 10 percent or more and lesser interests where such ownership confers *de facto* control is sufficient to ensure proper attribution of spectrum holdings."[176] Such an *ipse dixit* does not remotely provide evidence that could survive judicial review.[177] And, such a low attribution threshold will "discourage important, but competitively insignificant investments in wireless carriers . . . ."[178]

Nor can the Commission adopt MetroPCS's self-serving suggestion that a lower attribution threshold can be applied to AT&T and Verizon—but no other carrier—because of their "large" market share. The mobile wireless marketplace is intensely competitive, and the fact that AT&T and Verizon have achieved a larger share of customers does not demonstrate that these carriers wield market power. MetroPCS concedes that the 10 percent attribution rule will not "give that stakeholder any meaningful influence over the licensee."[179] But if that is true—as it is—nothing would change based on the minority owner's "market share."[180]

---

[175] *See Notice* ¶ 41; *see also* AT&T Comments at 80-81.

[176] RTG Comments at 10.

[177] *See Alliance for Community Media v. F.C.C.*, 529 F.3d 763, 786 (6th Cir. 2008) (*citing Motor Vehicle Mfrs. Ass'n of U.S. v. State Farm Mut. Auto. Ins. Co.*, 469 U.S. 29, 43 (1983)).

[178] Clearwire Comments at 7; *see also* CCIA Comments at 23.

[179] MetroPCS Comments at 18.

[180] *Burlington N. & Santa Fe Ry. Co. v. Surface Transp. Bd.*, 403 F.3d 771, 777 (D.C. Cir. 2005) (noting that arbitrary agency action occurs when agencies "appl[y] different standards to similarly situated entities"); *see also Indep. Petroleum Ass'n v. Babbitt*, 92 F.3d 1248, 1260 (D.C. Cir. 1996) (agencies cannot "treat[] type A cases differently from similarly situated type B cases").

B. The Commission Should Apply Any New Restrictions on Spectrum Holdings Only to Future Transactions and on a Competitively Neutral Basis.

To the extent that the Commission adopts new attribution rules, or new aggregation policies generally, the Commission should not apply those new rules retroactively to existing holdings. Competition has flourished under the Commission's existing spectrum holding screens and attribution rules, even where providers have exceeded the "safe harbor."[181] In such circumstances, the Commission has previously recognized it would be "contrary to the public interest" to apply new attribution rules retroactively because of the potential for "disrupt[ion],"[182] and there is no reason to depart from that precedent here. Indeed, adopting rules "that called into question spectrum rights that were lawfully obtained under the Commission's then-existing spectrum aggregation policies could be enormously disruptive and—by creating uncertainty about the future application of retroactive rules—would very likely undermine investment incentives."[183]

---

[181] AT&T Comments at 81.

[182] Report and Order, *In the Matter of Amendment of Parts 20 and 24 of the Commission's Rules – Broadband PCS Competitive Bidding and the Commercial Mobile Radio Service Spectrum Cap*, 11 FCC Rcd. 7824, ¶ 132 (rel. June 24, 1996) ("*PCS Remand Order*") ("[R]etroactive application of any cross-ownership or spectrum cap rule changes would be contrary to the public interest.")

[183] Katz-Israel Decl. ¶ 120.

CONCLUSION

For the foregoing reasons, the Commission should amend its rules as described above.

Respectfully submitted,

/s/ Michael P. Goggin

David L. Lawson
James P. Young
C. Frederick Beckner III
Christopher T. Shenk
Sidley Austin LLP
1501 K Street, N.W.
Washington, D.C. 20005
(202) 736-8000

Michael P. Goggin
Gary L. Phillips
Peggy Garber
AT&T Inc.
1120 20th Street, N.W.
Washington, D.C. 20036
(202) 457-2055

Attorneys for AT&T Inc.

January 7, 2013

ATTACHMENT A

THE VALUE OF SPECTRUM

A RESPONSE TO PROFESSOR JON M. PEHA's PAPER

Jeffrey H. Reed[1] **and Nishith D. Tripathi**[2]

Reed Engineering

Abstract. This paper responds to the comments submitted to the Federal Communications Commission (FCC) by Professor Jon M. Peha relating to the spectrum screen that the FCC employs when evaluating requests by mobile wireless service providers to increase their spectrum holdings. Currently, the FCC counts all spectrum that is "suitable" and "available" for mobile wireless services the same. Professor Peha contends that the propagation characteristics of "low-band" spectrum (typically defined as spectrum below 1 GHz) make it more valuable than "high-band" spectrum (because low-band spectrum can potentially be deployed on more widely spaced cell sites, reducing infrastructure costs) and that low-band spectrum should therefore count more than high-band spectrum when computing a provider's total spectrum holdings. We respectfully disagree with this contention. As Professor Peha recognizes, in urban areas – where the demands on wireless networks are the greatest and the spectrum screen has the most impact – there is no low-band propagation advantage because small cell sizes are needed to meet capacity needs regardless of the frequency of the spectrum deployed. And although low-band propagation advantages can reduce the number of cell sites needed for coverage in some rural and suburban areas in the case of a green-field deployment, Professor Peha's use of simplifying assumptions that depart radically from real world deployment practices yields results that greatly exaggerate these differences (and completely ignore myriad other factors that impact spectrum value). We agree with the conclusions of the economists that have studied this issue and have pointed out that to the extent material propagation-related differences in spectrum value exist, they will be reflected in the prices paid for the spectrum licenses (as Professor Peha's own analysis confirms), and that it would thus be wrong for the FCC to account for those same differences a second time in the spectrum screen.

---

[1] Professor Jeffrey H. Reed is the Director of Wireless at Virginia Polytechnic Institute and State University ("Virginia Tech") and the Willis G. Worcester Professor of Electrical and Computer Engineering at Virginia Tech. Professor Reed's vita is attached.

[2] Professor Nishith Tripathi is a principal consultant at Award Solutions, a provider of technical consulting and specialized technical training for wireless communications. Professor Tripathi is also an Adjunct Assistant Professor at Virginia Tech. Professor Tripathi's vita is attached.

1. EXECUTIVE SUMMARY

AT&T has asked us to examine the paper submitted by Professor Jon M. Peha filed in Federal Communications Commission (FCC) Docket Nos. 12-269 and 11-186 on November 28, 2012 on behalf of Public Knowledge. Professor Peha's submission aims to provide technical support for claims that the Commission should change the way it computes the FCC's "spectrum screen." Under the FCC's current methodology, all spectrum suitable and available for mobile services is treated equally in the screen, *i.e.* the screen "safe harbor" is computed by summing all suitable and available spectrum and dividing by three. If a spectrum transaction does not result in spectrum holdings exceeding this safe harbor in a given area, then the resulting spectrum aggregation is deemed unobjectionable.

Professor Peha's submission attempts to provide engineering support for arguments that the FCC should change the way it computes the spectrum screen to give more weight to "low-band" spectrum (typically defined as spectrum below 1 GHz) than to "high-band" spectrum (above 1 GHz) because, according to proponents of this approach, low-band spectrum is inherently more valuable than high-band spectrum.

In our view, the economic testimony in this proceeding provides a complete answer to this argument.[3] To the extent it actually costs more to deploy high-band spectrum in certain areas, the high-band spectrum licenses in those areas can be expected to sell for less than low-band spectrum licenses, and the difference in those prices will reflect the differences in the cost of deploying the spectrum. As the economists point out, because the deployment cost differences about which Professor Peha is concerned are already accounted for in the price of the spectrum licenses, it is difficult to conceive a legitimate basis to account for any such differences a second time via the spectrum screen.

In this paper, however, we focus on the lack of technical or engineering bases for claims that low-band is inherently more valuable than high-band spectrum. In fact, Professor Peha *agrees* that in urban areas (where spectrum needs tend to be the greatest), there is no engineering basis for the notion that low-band spectrum is more valuable than high-band spectrum. Indeed, as we explain below, the low-band spectrum propagation "advantage" upon which Professor Peha focuses may actually prove to be a disadvantage in urban areas. Thus, at least for urban areas, the technical premise for weighting low-band spectrum more than high-band spectrum when computing the spectrum screen simply does not exist.

---

[3] Mark A. Israel and Michael L. Katz, Economic Analysis of Public Policy Regarding Mobile Spectrum Holdings, ¶¶ 91-92 (Nov. 28, 2012) ("Israel/Katz Paper"), attached as "Attachment A" to Comments of AT&T Inc., Policies Regarding Mobile Spectrum Holdings, WT Docket No. 12-269 (Nov. 28, 2012); Mark A. Israel and Michael L. Katz, Supplemental Economic Analysis of Public Policy Regarding Mobile Spectrum Holdings (Jan. 7, 2013) ("Israel/Katz Supplemental Paper"), attached as "Attachment B" to Reply Comments of AT&T Inc., Policies Regarding Mobile Spectrum Holdings, WT Docket No. 12-269 (Jan. 7, 2013).

Professor Peha, therefore, does not argue that there is any engineering or technical basis for giving low-band spectrum greater weight than high-band spectrum in urban areas. Instead, he makes the following three step argument: (i) there are technical and engineering bases for concluding that low-band spectrum is more valuable than high-band spectrum in rural areas and in some suburban areas; (ii) it may not be feasible or desirable to develop a separate screen for rural, suburban, and dense urban areas; and (iii) the FCC could thus adopt a single weighting scheme that applies everywhere, including in dense urban areas.

The main problem with this analysis is that, even if it were true that low-band spectrum is always more valuable than high-band spectrum in rural and suburban areas (this is not accurate in typical practical deployments, as we explain below), it does not follow that the FCC should adopt a weighting scheme that applies everywhere, including in dense urban areas. Such an approach would be a classic case of the tail wagging the dog. Most wireless traffic and, accordingly, the greatest demands for wireless spectrum are located in dense urban areas. Therefore, if the FCC were to adopt a single spectrum aggregation policy based on a subset of areas in the country, it should adopt its policy based on circumstances in dense urban areas – where a spectrum screen or cap is most likely to be relevant and where Professor Peha himself finds no basis for giving more weight to low-band in the screen – not on circumstances that are claimed to exist only in areas where wireless demand is much lower and the availability of spectrum is least likely to constrain entry and expansion.

In any case, Professor Peha's analysis can not be relied upon to conclude that low-band spectrum will necessarily be more valuable in rural or suburban areas. Professor Peha correctly recognizes that there is no feasible approach that could properly capture the many important and constantly evolving factors that affect the value of spectrum, and he therefore adopted a simplifying and unrealistic assumption that network operators will value spectrum solely by the costs of deploying and operating cells sites in green-field deployments. Moreover, even in estimating cell site costs, Professor Peha's conclusions are based on unrealistic assumptions as to how mobile networks are configured and deployed (Section 3, below), as well as incorrect applications of the Hata Path loss model and the Shannon limit (Section 4, below). More fundamentally, Professor Peha's analysis does not even address the relative value of high-band mobile spectrum that is actually used successfully in the U.S. today, *e.g.,* AWS (1700/2100 MHz), PCS (1900 MHz), WCS (2100 MHz), and BRS/EBS (2500 MHz). As Professor Peha explains, analyses of "frequency bands above 1500 MHz . . . are beyond the scope of this comment."[4]

Professor Peha's analysis produces clearly invalid results when extended to U.S. mobile high-band spectrum. The formulas used by Professor Peha to compute the value of 1.5 GHz spectrum – the highest frequency band he analyzed – when extrapolated beyond 1.5 GHz, appear to predict that the vast majority of the high-band spectrum actually used in the U.S. would have *negative* value. In effect, his analysis indicates that the FCC could not even give

[4] Jon M. Peha Comments, Updating the Spectrum Screen: Comments for Public Knowledge, *Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269, at 11 (Nov. 28, 2012) ("Peha Comments").

away certain AWS spectrum in rural and suburban areas, a notion that we do not find to be credible, particularly given that AWS spectrum routinely changes hands in secondary market transactions at high prices.

Finally, Professor Peha suggests that the FCC should also consider collecting and using the number of cell towers per square kilometer deployed by a carrier in each spectrum band to assess whether the carrier is "warehousing" spectrum. He states that "[i]f this number is considerably lower than can be seen from competitors in the same region or simply low considering other relevant factors, and the carrier is still trying to expand its spectrum holdings, then this could be an indicator that spectrum is being warehoused."[5] He admits, however, that such a statistic is only "[p]otentially useful" as a warehousing indicator.[6] In our view, such a crude statistic would not be useful at all, because there are numerous legitimate technical reasons why one network operator may be using a smaller number of cell towers than competitors in the same area.

2. THE DATA CARRYING CAPACITY OF SPECTRUM

Professor Peha's paper challenges the following argument made by AT&T against different weightings for high and low-band spectrum in the FCC's spectrum screen:

> The spectrum screen has always been properly focused on spectrum *capacity*, not nebulous notions of 'value.' . . . The data-carrying capacity of all spectrum, however is equal: 20 MHz of AWS spectrum can carry as much wireless broadband data traffic as 20 MHz of 700 MHz spectrum. Accordingly, the spectrum screen must count all spectrum equally; weighting the spectrum on any other basis would produce a grossly distorted picture of the economic impact of a spectrum transaction.[7]

This statement is absolutely true from a wireless engineering standpoint in that the overall data-carrying capacity of spectrum used in cellular networks is essentially the same for all spectrum bands, including spectrum that is below and above 1-GHz. The capacity (*i.e.*, the number of simultaneously active users) or average throughput (*i.e.*, the average bits per second supported) is not defined by the spectrum frequency, but rather is a function of the signal-to-interference plus noise ratio (SINR or SIR) that can be achieved. The greater the signal to noise ratio, the greater the capacity and throughput, and the lower the signal-to-noise ratio, the lower the capacity and throughput.

There is no inherent difference between high-band and low-band spectrum that prevents network operators from achieving similar SIRs within their networks, and thus achieving the

[5] Peha Comments, at 15.

[6] Peha Comments, at 15.

[7] Peha Comments, at 3 (citing Supplemental Reply Comments of AT&T, *The State of Mobile Wireless Competition*, WT Docket No. 11-186, at 5 (April 30, 2012)).

same or similar capacity and throughput levels per MHz of deployed spectrum. Network operators have numerous tools at their disposal for achieving their target SIR levels, including, among others, managing cell sizes, antenna gains, antenna beamwidths, antenna down-tilts, and antenna heights for the cells (or sectors) in a given geographic area. By managing these parameters, a network operator using high-band spectrum can typically achieve similar SIRs – and hence similar capacity and throughput – to a provider using low-band spectrum.

Professor Peha appears to agree with the importance of SIR. Although he asserts that "the maximum data-carrying capacity of a 20 MHz point-to-point link is generally much greater in the 700 MHz band than in the higher-frequency AWS band," he correctly acknowledges in the same sentence that this is true only "as long as there is no change in distance between transmitter and receiver, antenna gains, transmit power, and interference level."[8] In real world deployments, network operators using AWS spectrum do adjust the distances between transmitter and receiver (*i.e.,* cell sizes) and the antenna parameters (*e.g.*, antenna gain, down-tilting, beamwidth, and azimuth) to influence desired signal levels, and interference levels to permit them to achieve the same or similar capacity and throughput as a 700 MHz deployment using the same amount of spectrum. As Professor Peha admits, for example, "[i]t is literally the defining principle of a cellular system that the system is made up of cells, and capacity can be increased with no additional bandwidth simply by deploying more cells."[9]

Professor Peha's analyses therefore focuses on the relative *costs* of deploying high-band and low-band spectrum. In Professor Peha's words: "[t]he issue is cost; adding a cell may mean spending one million dollars on a new cell tower" and "[i]t is this relationship to cost that should be the basis of a spectrum screen and the focus of [the FCC's] NPRM."[10]

In our view, the economic testimony in this proceeding provides a complete answer to this argument. As explained by Professor Katz and Dr. Israel, to the extent that it actually costs more to deploy high-band spectrum in a given area, those high-band spectrum licenses will sell for less than low-band spectrum licenses, and the difference in those prices should reflect the present value of any differences in the cost of deploying those facilities. The cost differences about which Professor Peha is concerned are thus already accounted for in the prices of the spectrum licenses, and we see no conceivable basis to account for any such differences a second time via the spectrum screen.[11]

Our expertise, of course, is wireless engineering, and the rest of this paper focuses on the Professor Peha's engineering analyses.

---

[8] Peha Comments, at 3.

[9] Peha Comments, at 3.

[10] Peha Comments, at 3-4.

[11] Israel/Katz Paper, ¶¶ 91-92; Israel/Katz Supplemental Paper, ¶¶ 22-26.

3. THE MANY WIRELESS ENGINEERING FACTORS THAT CAN AFFECT SPECTRUM VALUATION

Professor Peha correctly recognizes that "one cannot say that one frequency is better than another without considering the types of wireless systems to be deployed."[12] Although the value of spectrum will depend in part "on frequency and bandwidth," it also depends on "how the spectrum band is fragmented in frequency and geography," "what equipment is available in the band, which depends in turn on the extent to which regulators around the world have allocated the band for the same purpose, and for how long it has been used by CMRSs,"[13] as well as "the technical and business strategy of every carrier in the market."[14] Indeed, Professor Peha ultimately states correctly that "there are too many factors to consider explicitly" and that to make matters worse, some of those factors "can change rapidly" over time.[15]

To "simpli[fy]" his analysis, Professor Peha, therefore, considers only how providers might value spectrum in extremely narrow circumstances. In particular, his analysis implicitly assumes that the hypothetical purchasers of spectrum will be building out an entirely new green-field network in an area where there are no existing cell towers, such that the hypothetical purchasers will have to build and operate all new cell sites when they seek to deploy new spectrum. He concludes that in these narrow circumstances, the marketplace will value low-band spectrum more than high-band spectrum in rural and some suburban areas. But the technical and engineering assumptions on which he draws these conclusions are not consistent with how providers typically deploy spectrum and his results are thus highly unlikely to reflect actual or relative valuations of high-band and low-band spectrum in a typical real world situation.

In the U.S., there are very few areas where people live that are not already covered by at least one wireless network – indeed, according to the FCC's most recent report on wireless competition, more than 97% of the U.S. population lives in areas served by three or more wireless providers.[16] In areas where at least one provider already has a network, it is highly unlikely that network operators will build from scratch and operate all of the cell sites needed to support the new deployment. In these areas, there will already be cell sites available for use in deploying new spectrum. Therefore, in the case where a provider is overlaying its existing network using high-band spectrum, the provider typically re-uses its existing cell sites, adding new ones only where it finds coverage holes or a need for additional capacity. Similarly, in the

---

[12] Peha Comments, at 4.

[13] Peha Comments, at 5-6.

[14] Peha Comments, at 5-6.

[15] Peha Comments, at 6.

[16] Fifteenth Report, Implementation of Section 6002(b) of the Omnibus Budget Reconciliation Act of 1993; Annual Report and Analysis With Respect to Mobile Wireless, Including Commercial Mobile Services, WT Docket No. 10-133, page 6 (released June 27, 2011), *available at* http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-11-103A1.pdf.

case where a provider does not have an existing network in a particular area, it still will not generally be necessary to build all of the cell sites needed to support the deployment. Rather, in most areas of the U.S., the provider would be able to colocate its equipment at *existing* cell sites owned by other providers or by cell site leasing companies. The provider will need to build new cell sites only in areas where deploying the new band on existing sites lead to coverage holes (or capacity constraints) or collocation at existing cell sites is not feasible (*e.g.*, because of space or weight limitations on the tower). Thus, Professor Peha's analysis, which is based entirely on the premise that network operators deploying new spectrum will be required to bear the entire cost of building and operating all of the cell sites needed to support that deployment, greatly overstates the relative costs of deploying service with low-band and high-band spectrum.[17]

In addition, in many real world scenarios, factors other than the costs of deploying and operating new cell sites may dominate any particular provider's valuation of spectrum for any particular area. For example, a provider that has an existing AWS network but no 700 MHz facilities may place much greater value on AWS spectrum than on 700 MHz spectrum in a given area, because the provider can integrate additional AWS spectrum into its network at a lower cost (*e.g.,* by avoiding the performance costs needed for handover from AWS to 700 MHz). By using AWS spectrum, the provider can also ensure backward compatibility with the AWS-compatible devices used by its existing customers. Furthermore, as we discuss below, providers will often prefer high-band spectrum in urban areas where cell sites tend to be smaller to help minimize inter-cell interference and to achieve the maximum benefits of technologies, such as MIMO, that enhance throughput and capacity.

In addition, greater amounts of high band spectrum are available making it easier for a carrier to gain efficiencies by securing contiguous blocks of spectrum, which can increase the value of high-band spectrum relative to low-band spectrum. LTE can be deployed more efficiently with large, contiguous spectrum blocks. LTE supports channel bandwidths of up to 20 MHz, and LTE-Advanced will support total channel bandwidth as wide as 100 MHz. LTE uses scalable Orthogonal Frequency Division Multiple Access (OFDMA) that provides larger cell throughput (and end user throughput) for larger bandwidths. For example, LTE can support a theoretical peak data rate of 300 Mbps in the downlink if the downlink channel bandwidth is 20 MHz; the theoretical peak data rate decreases to 150 Mbps if the channel bandwidth is constrained to 10 MHz (both estimates assume 4 X 4 MIMO). Narrower channel bandwidth is one of the main reasons why current and planned near term LTE deployments cannot realize the full potential

[17] We note that the FCC staff has recognized that cell site cost estimates should account for the fact that providers can use existing cell sites. *See, e.g.,* Mobile Broadband: The Benefits Of Additional Spectrum, FCC Staff Technical Paper, at 20, 24-26 (Oct. 2010) ("[W]e have not included the cost of new tower construction because it is likely that the majority of new cell-sites will leverage existing tower infrastructure to add capacity. This is consistent with our prior assumption that all new cell-site growth will be related to 'infill' sites, rather than those engineered to expand coverage."), available at http://download.broadband.gov/plan/fcc-staff-technical-paper-mobile-broadband-benefits-of-additional-spectrum.pdf.

of LTE. A contiguous bandwidth of a certain size is more efficient than two non-contiguous channels that total the same size. The use of contiguous blocks permits the provider to allocate less spectrum to overhead and support. For example, if a provider deploys two separate LTE channels, some overhead – such as synchronization signals, the physical broadcast channel, and system information – would be effectively duplicated on two channels, thus reducing the achievable throughput. Furthermore, only one channel can be assigned to a Release 8 LTE device, limiting the peak throughput available to any given device.

Regulatory requirements may also have a significant impact on a provider's relative valuation of high and low-band spectrum that may dominate other considerations. For example, as we understand the FCC's build-out requirements, 700 MHz A and B block licensees are required to build out a network that covers 35 percent of the *geographic area* where the spectrum licenses are held within 4 years, and 70 percent of the geographic area by the end of the lease term.[18] By contrast, the FCC's rules for some high-band spectrum bands require only that the provider offer "substantial service" by the end of the licensed term, which can be 10 or more years.[19] These different build out requirements can mean that purchasers of low-band spectrum must build out services more quickly and in a much larger geographic area than purchasers of high-band spectrum, which can result in higher costs for low-band spectrum license holders than for high-band spectrum license holders.

It is also important to recognize that carriers typically purchase spectrum many months or years before they are able to deploy it. Accordingly, a purchaser's valuation of spectrum would presumably reflect the costs of deploying that spectrum in the future, when different technologies will be available. For example, LTE-Advanced may impact the cost equation with "Self Organizing Networks" that reduce the capital expenditures and operational costs of the increasing number of base stations necessary to cover a region.[20]

Recent real-world spectrum transactions confirm that considerations other than the number of cell sites that would have to be built in areas where no carrier has deployed a network in the U.S. can dominate the perceived relative value of high and low-band spectrum. For example, Verizon recently purchased large amounts of high-band AWS spectrum, and to gain regulatory approval for doing so it agreed to divest certain low-band 700 MHz spectrum. And, as part of that transaction, T-Mobile agreed to purchase AWS spectrum from Verizon, even though it could have instead purchased the 700 MHz spectrum that Verizon had agreed to divest.

Lastly, in addition to relying on oversimplified assumptions as to how network operators value high-band and low-band spectrum, Professor Peha's analysis is deficient in an even more

---

[18] *See* 47 C.F.R. §27.14.

[19] *See* 47 C.F.R. §27.14.

[20] Self-Organizing Networks (SONs) provide automatic adjustments, optimization, and fault-recovery of eNodeBs (*i.e.,* LTE base stations) and development occurring that allows cells sites, particularly small cells sites, to optimize parameters such as Physical Cell Id (PCI) and handover parameters.

fundamental way: it does not analyze high-band spectrum that is actually used in the U.S. for mobile broadband services. Professor Peha expressly disclaims having done any analysis of high-band frequencies used in the U.S.: "[analyses of] frequency bands above 1500 MHz . . . are beyond the scope of this comment."[21] As such, Professor Peha omits any analysis of AWS, PCS, WCS, EBS/BRS spectrum or any of the other high-band spectrum frequencies currently allocated for mobile services in the U.S.

4. PROFESSOR PEHA'S VALUATION MODELS FOR URBAN, RURAL AND SUBURBAN AREAS

Professor Peha explains that the results of his analysis will vary depending on many factors. He explains that "probably the most important" factor affecting the results of his limited analysis "is population density."[22] Accordingly, Professor Peha analyzes "dense urban," "rural," and "suburban" areas separately. In this section, we examine his analyses for each of these areas.

4.1. Urban Areas. Professor Peha agrees that there is no engineering basis for treating high-band and low-band spectrum differently when computing the spectrum screen for urban areas.[23] Professor Peha correctly recognizes that in urban areas, cell size (and hence the cost of deploying cell sites) is not driven by the propagation characteristics of spectrum, but by demand for capacity. To meet the demand for capacity in urban areas, cell sizes must be small, which negates any propagation benefits of low-band spectrum.[24] In Professor Peha's words, in the case of dense urban areas "frequency has little impact on the number of towers" and the "value of a MHz-POP of spectrum when used for this purpose," *i.e.,* dense urban deployment, "should be roughly the same in all frequency bands used by this carrier."[25] For these reasons, Professor Peha agrees that there is no technical basis for applying a greater weight to low-band spectrum when computing the spectrum screen for urban areas.

In fact, there can be significant advantages to using high-band spectrum in urban areas that can make it *more* valuable than low-band spectrum. For example, low-band spectrum can be more susceptible to inter-cell interference than high-band spectrum, which can increase the performance cost of deploying low-band spectrum relative to high-band spectrum in areas with small cell sites. In a cellular deployment of technologies such as LTE, UMTS, 1xRTT, and 1xEV-DO, adjacent cells (*i.e.*, sectors) use the same radio channel (*e.g.*, a 10 MHz channel at the 700 MHz band). It is therefore important that networks are configured in a manner that minimizes the extent to which signals generated from a base station in one cell extend into another cell.

---

[21] Peha Comments, at 11.

[22] Peha Comments, at 6.

[23] Peha Comments, at 9.

[24] This is an example of the principle of frequency reuse, which is a defining characteristic of cellular networks. By using more base stations in the same spectrum band in the same area and by reducing the effective coverage of each of those base stations, the same spectrum frequencies can be "reused" more often.

[25] Peha Comments, at 9.

Where signals from a base station in an adjacent cell enter a cell where a mobile device is operating, that device will receive signals from two or more base stations: (1) the base station within the cell in which the device is operating and (2) the base station(s) from the adjacent cell(s). The signal from the base station(s) in the adjacent cell(s) would constitute interference, and will interfere with the device's ability to communicate with the base station within its cell, resulting in degraded throughput and decreased capacity.

Inter-cell interference can be a problem for both low-band and high-band deployments, but as a general matter, it is a more challenging issue for low-band deployments because, as Professor Peha recognizes, low-band spectrum typically propagates further than high-band spectrum. To mitigate inter-cell interference, network operators tune the various parameter of their network (*e.g.,* antenna down-tilting). Due to the propagation characteristics of low-band spectrum, more tuning – and hence greater RF engineering efforts – may be required for low-band spectrum to minimize inter-cell interference. For these same reasons, more extreme mitigation measures are often needed to mitigate inter-cell interference for low-band networks, *e.g.,* antennas may require significantly more down-tilting for a low-band deployment than for a high-band deployment. As a result, for low-band deployments, it will more often be the case that the limits of mitigation techniques would be reached before inter-cell interference is sufficiently mitigated, and in these instances, low-band networks are subject to greater interference than corresponding high-band networks. In short, it can sometimes be more costly to minimize inter-cell interference for low-band networks than for high-band networks in dense urban areas, and it can be infeasible to avoid such interference completely when using low band spectrum. Professor Peha's analysis does not account for these factors.

Other factors may also make high-band spectrum relatively more valuable in urban areas with small cell deployments. For example, Multiple Input Multiple Output (MIMO) systems – which permit greater throughput and capacity – tend to be more effective in multipath-rich environments (*e.g.*, small cells in urban areas) due to the diversity of multipath sources and the ability to support multiple antennas on the handset with reduced spacing needed between antennas.[26] In these urban areas, the signals received at antennas in a small form-factor mobile device would be relatively uncorrelated at higher frequencies due to shorter wavelengths (and more correlated at lower bands). The MIMO performance would generally be better at a higher band than at a lower band, which would tend to increase the value of high-band spectrum relative to low-band spectrum in a multipath-rich environment.

Notwithstanding Professor Peha's acknowledgment that there is no technical basis for concluding that low-band spectrum will be more valuable than high-band spectrum in dense urban areas, he stops short of agreeing that FCC's spectrum screen should weight all spectrum equally in urban areas. Professor Peha argues that, although there is no basis for giving more weight to low-band spectrum in urban areas, his analysis found a basis for doing so in rural and

[26] *See* Real Wireless, 4G Capacity Gains, Report Submitted to Ofcom, January 2011, available at http://stakeholders.ofcom.org.uk/binaries/research/technology-research/2011/4g/4GCapacityGainsFinalReport.pdf.

in some suburban areas. He argues that it might be impractical or undesirable to apply a different weighting mechanism in urban areas than in rural and suburban areas and that the FCC might, for reasons of administrative convenience, apply a single weighting approach in all areas.[27]

In our view, however, any such approach that would apply weights to the spectrum screen in urban areas based on supposed differences in deployment costs in some rural or suburban areas in a green-field deployment would be a classic case of the tail wagging the dog. The vast majority of mobile services subscribers and demand are located in more urban areas (and similarly high traffic suburban areas), not in more rural areas. Therefore, even if we were to follow Prof. Peha's approach, any uniform weighting scheme should *not* be driven by the weights appropriate for rural areas (and any low traffic suburban areas), but by the weights that are appropriate for urban areas.

In any case, Professor Peha proposes no specific weights, nor any specific formula for how such a uniform weighting scheme (or any other weighting scheme) could be implemented. To the contrary, he explains that "there are too many factors to consider explicitly" to develop such weights, and to make matters worse "some of them can change rapidly" over time.[28] He explains, for example, that "the value of a spectrum band in facilitating low-cost infrastructure deployment" depends on "how the band is fragmented in frequency and geography," "what equipment is available in the band, which depends in turn on the extent to which regulators around the world have allocated the band for the same purpose, and for how long it has been used by CMRSs," and "the technical and business strategy for every carrier in the market."[29] In short, Professor Peha neither provides a practical engineering basis for a weighting scheme, nor a specific approach for computing such weights.

4.2. Rural areas. Professor Peha argues that in contrast to urban areas, cell sizes in rural areas are not constrained by demand and thus can be as large as the propagation characteristics of spectrum will permit. Based on this assumption, he contends that networks using low-band spectrum will cost less than networks using high-band spectrum, because low-band spectrum permits the use of larger cell sizes and hence will require building and operating fewer cell sites. On this basis, he concludes that low-band spectrum should be viewed as much more valuable in rural areas.

---

[27] Peha Comments, at 12 (explaining the "major disadvantages" of attempting to apply a different weighting scheme for urban, rural, and suburban areas: "First some regions considered in merger reviews may be large enough that they contain a mix of urban, suburban and rural. If so, having multiple screens would only confuse the issue. Second, handsets can typically operate in a limited number of spectrum bands, so there are advantages to using the same spectrum bands in both urban and rural areas, even if the impact on infrastructure cost is different").

[28] Peha Comments, at 6.

[29] Peha Comments, at 5-6.

Professor Peha's analysis of the relative value of high and low-band spectrum in rural areas has several shortcomings. He begins with the premise that "[t]he maximum possible radius of a cell is the maximum distance from cell tower to mobile device at which the signal to interference + noise ratio (SINR) is adequate."[30] He then uses the Hata Model for path loss to compute the relative sizes of cells that can be deployed (assuming no capacity constraints) for low-band and high-band frequency spectrum. As a baseline, he assumes that a 700 MHz LTE network can be deployed in rural areas using a cell radius of 80 km. In Figure 1 of his paper, he depicts the results of these computations, which show that more cell sites are needed for high-band spectrum than for low-band spectrum. Next, Professor Peha computes the per MHz-POP cost of deploying that number of cell sites based on the assumption that the net present value (NPV) of a greenfield cell site is about $1 million. In Figure 2 of his paper, he depicts the results of these computations, which show that infrastructure costs are higher for high-band spectrum deployments than for low-band spectrum deployments. Using these data, Professor Peha lastly computes the impact of spectrum valuations "in a specific scenario."[31] Specifically, he estimates the relative value per MHz-POP for high-band and low-band spectrum for a 10 MHz block in an area with 7.4 people per square km, and based on the assumption that, as a baseline, the value of 700 MHz spectrum in such a rural area is $1.15 per MHz POP. The results of this analysis are shown in Figure 3 of his comment paper.

To begin with, as explained above, Professor Peha expressly disclaims having conducted any analysis to determine the relative values of low-band spectrum and high-band spectrum that is actually used for mobile services in the U.S. (*i.e.,* AWS, PCS, WCS, and BRS/EBS). Rather, Professor Peha explains that "[analyses of] frequency bands above 1500 MHz . . . are beyond the scope of this comment."[32]

Further, a simple reality check confirms that his analysis clearly produces invalid results when extended to the high-band spectrum used in the U.S. According to Figure 3 in Professor Peha's paper (which we replicate below), the highest spectrum shown in the figure – 1.5 GHz spectrum – would be valued at just over $0.25 per MHz-POP. Following the trend line shown in the figure, however, reveals that the value of the vast majority of high-band spectrum used to provide mobile services in the U.S., which are all above 1.5 GHz, would have *negative* value under Professor Peha's analysis. It is therefore clear that Prof. Peha's analysis cannot be extrapolated to estimate the relative value of low-band and high-band spectrum used for mobile services in the U.S.

[30] Peha Comments, at 7.

[31] Peha Comments, at 9.

[32] Peha Comments, at 11.

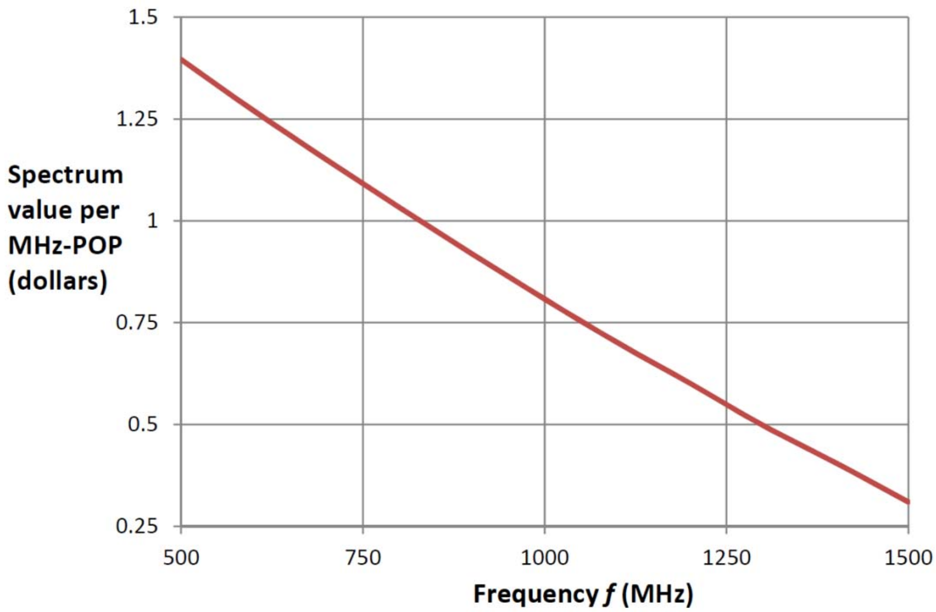


Figure 1. A Copy of Figure 3 From Professor Peha's Comment.

As we explained in Section 3, above, there are a number of reasons why Professor Peha's analysis produces such clearly unusable results. For example, he incorrectly assumes that providers deploying high and low-band spectrum in rural areas will have to incur the costs of deploying and operating all of the cell sites needed for the service, when, in fact, carriers will use their existing cell sites or will colocate at the cell sites owned by tower companies or other carriers. He does not account for regulatory buildout and other provisions that may affect providers' perceived value of spectrum. Nor does he account for the myriad unique circumstances that may affect any particular provider's relative valuation of high and low-band spectrum, including, for example, existing spectrum, system architecture, and the features of legacy embedded devices.

Professor Peha's analysis also assumes extremely unrealistic cell site coverage for 700 MHz deployments – which he uses as base line levels for his analysis – that greatly exaggerate the difference in the relative number of cell towers (and hence costs) of low and high-band networks. Professor Peha's analysis is based on the assumption that 700 MHz deployments will use 80 km (*i.e.,* about 50 miles) radii, which means that each cell would cover more than 16,640 square km (*i.e.,* more than 6,500 square miles), assuming hexagonal cells. In other words, Professor Peha assumes that a single cell would cover an area that is about *one hundred times* larger than Washington, D.C., and, indeed, larger than the entire state of Connecticut. Given the curvature of the earth, the base station antenna for such a system in a flat area of the central plains, for example, would have to be placed more than 500 meters high (*i.e.,* 1,650 feet) – that is taller than the Empire State Building (with the roof height of 381 meters and the overall height of 443 meters including the antenna spire).[33]

We are unaware of any 700 MHz (or any other mobile frequency) U.S. mobile wireless deployment with 80 km cell radii. Based on discussions with AT&T, we understand that AT&T's 700 MHz LTE deployment is based on LTE "Preamble Format 0,"[34] which has a maximum cell radius of 14.5 km – in other words, the base station will not even recognize a handset that is more than 14.5 km from the base station – and that in real-world rural deployments AT&T's design guidelines for 700 MHz LTE networks actually use cell radii that are much smaller than the Preamble Format 0 limits. Moreover, we understand from AT&T engineers that in areas where it is using both high-band spectrum and low-band spectrum, AT&T is seeking ultimately to match cell sizes, such that there would be no difference in cell sizes for high and low-band networks. Such matching enhances network performance (*e.g.*, fewer handovers and better throughput) and makes network planning, maintenance, and optimization easier.

There are also technical problems with Professor Peha's application of the Hata path loss model on which his conclusions are premised. The Hata path loss model estimates path loss (reduction in a wireless signal measured in dB) based on a number of inputs, including, for example, frequency, antenna gain, antenna height, transmit power, and noise/interference.[35] When applying this model, Professor Peha made the "simplifying assumption" that a provider would set all of these tunable parameters at the same level for both low and high-band spectrum.[36] This simplifying assumption, however, is highly unrealistic, and Professor Peha's reliance on it substantially understates the true coverage potential for high-band spectrum as compared to low-band spectrum. The antenna parameters, including the base station antenna height and antenna gain, are typically tuned to ensure adequate coverage. Providers using high-band spectrum may seek out greater antenna heights and use higher antenna gain levels to increase the size of the cells that can be served by a single site. At the same time, a provider using low-band spectrum may seek out lower antenna heights and lower antenna gain levels to minimize potential inter-cell interference (discussed above). These adjustments will tend to reduce the difference in cell sizes for high-band and low-band spectrum.

For all of these reasons, Professor Peha's simplifying assumptions substantially exaggerate the difference in cell sizes for any realistic deployments of high-band and low-band spectrum. At

[33] Shorter cell towers could be used if they were placed on mountaintops, but in mountainous areas, it would be virtually impossible to achieve 80 km radii coverage because the signals would be blocked by the mountains.

[34] LTE defines four preamble formats, 0 to 3, to support four different maximum cell sizes. The User Equipment uses the preamble format to determine how it should use the common uplink channel called the Physical Random Access Channel (PRACH).

[35] Peha Comments, at 7.

[36] Peha Comments, at 7.

best, they represent a potential hypothetical architecture that is not realistically appropriate in any real-world U.S. deployment.

4.3. Suburban Areas. Professor Peha's analysis of suburban areas is also based on a very narrow set of assumptions that do not reflect real-world deployments. His analysis first assumes that there are a fixed number of cell towers located in the more densely populated parts of suburban areas. He then examines the extent to which a low-band spectrum placed at these cell towers will be able to provide a given level of throughput at various distances from these cell towers.

The upshot of Professor Peha's analysis appears to be simple: because low-band signals propagate farther than high-band signals, low-band spectrum is more valuable. But as we saw in the case of urban deployments, propagation characteristics of spectrum alone do not define the value of spectrum. For example, we showed above that in urban deployments cell sites must be relatively small, such that the propagation benefits of low-band spectrum are negated, and may even become a liability.

The same factors that control the relative cost of deploying low-band and high-band spectrum in urban areas, could also cause the cost of deploying low-band spectrum in suburban areas to be similar to or even greater than the costs of deploying high-band spectrum. The relative cost of deploying spectrum in suburban areas will depend largely on the extent to which there are densely populated or high use areas within the suburban topology. For example, many suburban areas, including, for example, suburbs of Washington D.C., New York City, Chicago, and Los Angeles, are densely populated and are thus likely to require relatively small cell sizes that, as in urban areas, negate the propagation benefits of low-band spectrum. In addition, suburbs also often contain commuter routes that must be able to handle very large volumes of traffic during rush hours, and thus require small cell sizes that will often negate any propagation benefits from the use of low-band spectrum.

In these more densely populated suburbs, the relative cost of deploying high-band and low-band spectrum will be closer to those in urban areas, *i.e.,* the same or with low-band being more costly to deploy. To be sure, there will also be less densely populated portions of suburban areas where low-band spectrum could be deployed using fewer cell sites than higher band spectrum, such that lower band spectrum may be less costly to deploy in a green-field deployment. However, as we demonstrated above, whether and the extent to which low-band spectrum would be more valuable in these areas depend on numerous other factors, including the type of deployment, availability of existing cell sites for collocation, and the impact of the FCC's buildout rules.

Most suburban areas will likely have a mix of densely populated areas and more sparsely populated areas. The difference in the cost of deploying low-band and high-band spectrum – and hence their relative value under Professor Peha's analysis – in these areas will depend largely on the portion of the suburban area that is densely populated compared to those that are not. For example, in suburbs that have many densely populated areas, the benefits of using high-band spectrum in the densely populated areas may outweigh any benefits of using low-band spectrum in more rural areas, with the net result being that high-band spectrum would likely be more valuable (or both low-band and high-band would be equally valuable).

Professor Peha's paper does not address these relevant issues. As noted, he examined only the extent to which low-band spectrum may be able to offer greater throughput at greater distances from the cell site than high-band spectrum, all else being equal. He concedes that this analysis cannot determine the extent to which "the value of high-frequency spectrum" might be lower than low-frequency spectrum in suburban areas, because that "depends on a variety of factors."[37]

Moreover, Professor Peha's results for suburban areas are driven by various unrealistic assumptions. As noted, Professor Peha's analysis is based on a network with a fixed number of cell towers located in urban areas, where both high-band and low-band antennas are placed. According to Professor Peha, customers located near the cell tower will be served by the high-band spectrum, and customers located farther away from the cell towers will be served by lower band spectrum. In other words, Professor Peha envisions a network where some areas are covered by both high-band and low-band spectrum, and others are covered by only low-band spectrum.

While it is possible to use such a network design philosophy, it would be far from optimal. Such a network would require devices to frequently switch between the high-band network and the low-band network as they move between the areas that served by both frequencies and the areas served by only one of the frequencies. Managing such inter-frequency handover would require more overhead compared to intra-frequency handover, thus resulting in sub-optimal use of the spectrum. A single-receiver LTE device (or User Equipment ("UE")) can be present on only one carrier frequency at a time. To enable a UE to seamlessly move across different carrier frequencies, LTE allows the eNodeB (*i.e.,* the LTE base station) to configure a UE with a measurement pattern that includes a gap during which the UE being served on a carrier frequency, say frequency "fx", can make measurements of a different carrier frequency, say frequency "fy". During such gaps, the UE is absent from the air interface of the serving frequency fx and no uplink or downlink data transfer can occur. The average throughput would thus be lower in such a scenario compared to the intra-frequency scenario that does not need any such measurement gaps. Two measurements patterns are defined in LTE with the same gap of 6 ms but with two different measurement cycles of 40 ms and 120 ms. The overhead would then be 5% or 15% depending upon the configured measurement cycle and throughput would be reduced approximately by these amounts. Since the UE needs to switch between the frequencies, it would also consume more processing power. The overall signaling overhead could also be somewhat higher in the case of inter-frequency handover compared to intra-frequency handover.

Based on our discussions with AT&T, for example, AT&T's long term deployment plans seek to ensure full coverage for both its high and low-band spectrum in suburban (and other areas) where it is deploying both types of spectrum. That is, AT&T's LTE network will support

[37] Peha Comments, at 11.

maximum throughput within the geographic area for both high-band and low-band spectrum, so that it will not ordinarily be necessary for the network to change the frequency of a device as it moves through an area.

In addition to being based on an unrealistic deployment scenario, Professor Peha's approach to model the throughput for a hypothetical network is greatly oversimplified in a manner that exaggerates the differences in throughput for high-band and low-band spectrum deployments.

To estimate throughput (*i.e.,* the data rate), Professor Peha uses the Shannon Limit formula: Data Rate = Bandwidth * $\log_2(1+\text{SINR})$. As discussed above, SINR is the ratio of the desired signal to the interference plus noise. Accordingly, given a particular bandwidth, the maximum throughput according to the Shannon Limit is purely a function of the desired signal level and the interference plus noise level. Professor Peha then removes one of these variables from the analysis. He assumes the noise plus interference will be the same for both high-band and low-band networks in any given location, so that the only relevant determinant of SINR, and hence throughput, is the desired signal level. He thus concludes that because the desired signal level for low-band spectrum will be higher at any given location, the maximum throughput will then be higher for low-band spectrum than for high-band spectrum.

This analysis is incorrect in multiple respects. First, it is not accurate that noise plus interference levels will be the same for low and high-band signals, as his analysis implicitly assumes. Interfering low-band signal levels tend to be higher in any given location than interfering high-band signal levels, because (just like the desired signal) low-band interfering signals tend to propagate further than high-band interfering signals. Therefore, low-band interference levels tend to be higher in any given location than those of high-band signals. This means that even though the desired signal at a high-band may be weaker in a particular location than a low-band signal, the high-band network may still achieve the same or similar SINR, because the high-band interference levels will also be lower than the low-band interference levels. Thus, Professor Peha's analysis, by maintaining the levels for interference plus noise constant for high-band and low-band spectrum, leads to incorrect conclusions about SINR and throughput, and thus exaggerates the difference in throughput for low-band and high-band networks.

Second, Professor Peha's analysis fails to account for the fact that network operators typically design their networks – whether they are using high or low-band spectrum – to achieve a desired SINR, and hence throughput level, within their service areas so that their customers can obtain a minimum quality of service throughout the area. In areas where the desired signal is weaker and/or the interference level is high (*i.e.*, the overall SIR or SINR is low), the network operator will seek to increase the desired signal level and decrease the interference level to increase SINR, using various approaches such as altering the antenna tilt, antenna height, and antenna gain, and adding cells when necessary. Professor Peha's analysis, however, effectively assumes that network operators will use the same parameters (*e.g.*, downtilts, antenna gains, and so on) for both high-band and low-band networks, thus understating the actual SINR levels, and hence throughput, that can be attained in high-band networks compared to low-band networks.

Third, the Shannon Limit "peak" metric relied on by Professor Peha to compare throughput in high-band and low-band networks is not of much use in practice. A more relevant throughput metric in the real world is not peak throughput – which can typically be obtained only when a single user is engaged in a data session in the cell under the best possible radio channel conditions – but the attainable average (busy hour) throughput. Network operators typically design their networks to achieve target busy hour throughputs, not maximum theoretical throughput. And there is not a specific constant relationship between the maximum potential throughput (Shannon Limit) and the average throughput due to several factors. For example, users are typically located in different parts of the cell and therefore experience different channel conditions, and hence different SINRs. Furthermore, user devices are dynamically configured to use different antenna techniques (*e.g.*, diversity techniques or MIMO spatial multiplexing). And, users' devices are allocated different amounts of radio resources as fast as every 1 ms. All of these factors change the relationship between the Shannon limit data rate and the average cell throughput (and average user throughput).

5. THE RELEVANCE OF BUILDOUT

Professor Peha (with myriad caveats) suggests that the FCC should consider collecting and using the number of cell towers per square kilometer deployed by a carrier in each spectrum band to assess whether the carrier is "warehousing" spectrum. According to Professor Peha, "[i]f this number is considerably lower than can be seen from competitors in the same region or simply low considering other relevant factors, and the carrier is still trying to expand its spectrum holdings, then this could be an indicator that spectrum is being warehoused."[38] However, Professor Peha emphasizes that even he has doubts whether this statistic is a good indicator of warehousing, explaining that his analysis is only "[p]otentially useful" and that it "must be considered in the context of other factors."[39]

In our experience, there is no reason to assume any connection between the number of cell towers deployed and whether a provider is "warehousing" spectrum. There are many technical reasons why a carrier may be using fewer cell towers than competitors in the same area. Different operators may be using different technologies, and these technologies may have different link budgets. Different link budgets yield different maximum cell radii for coverage-driven deployments. Operators may have different design targets for the radio network planning (*e.g.*, different target cell-edge data rates and different cell-edge reliability targets). Additionally, while deploying a new technology, operators may have different initial coverage footprints to begin with based on previously deployed technologies. Operators may have added different numbers of capacity sites to meet the subscriber traffic demands and/or coverage requirements. Some sites may be undergoing transitions from an older generation of technology to a newer generation technology. Additionally, technology migration or transitions take a long time because of the need to move a vast majority of the older technology devices to

[38] Peha Comments, at 15.

[39] Peha Comments, at 15.

newer technology devices, preventing quick use of the older technology spectrum for a newer technology.

ATTACHMENT A

(Professor Reed CV)

Jeffrey H. Reed, Ph.D.

Willis G. Worcester Professor of ECE
The Bradley Department of Electrical and Computer Engineering
Director of Wireless at Virginia Tech
Virginia Tech
432 Durham Hall, Mail code 0350
Blacksburg, VA 24061
Voice: (540) 231-2972
FAX: (540) 231-2968
Email: reedjh@vt.edu
www.wireless.vt.edu
http://www.cnst.ictas.vt.edu/

Vitae

Section I: Experience & Education

Current Position:

Director of Wireless at Virginia Tech (Wireless@VT), 2005-present
Professor of the Bradley Department of Electrical and Computer Engineering, June 2002- Present
Interim Director, The Ted and Karyn Hume Center for National Security and Technolgy, January 2010 – May 2011
CEO and Co-Founder, Power Fingerprinting, Inc. 2011-Present
CTO and Co-Founder, Cognitive Radio Technology, 2007-present
Willis G. Worcester Professor, Bradley Dept. of Electrical and Computer Engineering, 2005-present

Professional Interest:

Research and teaching in signal processing and communication systems

Specific Research Interests	**Specific Teaching Interests**
Software Radios	Software Radios
Smart Antennas	Digital and Analog Communications
Interference Rejection	Discrete Time and Digital Signal Processing
Wireless Networks	Cellular and Personal Communications
Cognitive Radio	DSP-based Communication System Design
Location Technology	Adaptive Filtering

Education:

Ph.D.
Electrical and Computer Engineering, December 1987, University of California, Davis
Awarded American Electronics Fellowship for Faculty Development
Major: Statistical Signal Processing; Minor: Control Systems and Statistics
Dissertation: *Interference Rejection Using Time-Dependent Adaptive Filters*
Attended part-time at University of Santa Clara, September 1980 through June 1983

M.S.
Electrical and Computer Engineering, June 1980, University of California, Davis
M.S. Project Topic: An EEG Data Acquisition and Analysis System

B.S.
Electrical and Computer Engineering, March 1979, University of California, Davis

Employment:

Professor, Virginia Tech, April 2001-present
Director, MPRG 200-2002
Associate Professor, Virginia Tech, 1997-2001
President and co-founder, Power Fingerprinting, 2011 - present
CTO and co-founder, Cognitive Radio Technologies**,** 2007-present
Co-founder, Dot Mobile, Inc., March 2000-2001
Consultant, Reed Engineering (Self-Employed), 1987-present
Assistant Professor, Virginia Tech, 1992-1997
Research Engineer, University of California, Davis, 1992
Lecturer, University of California, Davis, 1988-1992
Associate Instructor, University of California, Davis, 1985-1987
Teaching Assistant, University of California, Davis, 1984-1985
Member of Technical Staff, Signal Science, Inc., Santa Clara, CA and Hanover, MD, 1980-1985

Professional Affiliations:

Member of **Tau Beta Pi Honor Society**
Member of **Phi Kappa Phi Honor Society**
Member of AFCEA
Fellow of the IEEE

Professional Awards:

Honorary lifetime membership in the Wireless Innovation Forum, 2012
Vehicular Technology Society Distinguished Lecturer 2011
Named Willis G. Worcester Professor of ECE, summer 2005, Fall 2010
Industry Achievement Award, SDR Forum 2004
Institute of Electrical and Electronics Engineers Fellow, Dec. 2004
Virginia Tech College of Engineering Outstanding Researcher Award, 2001

Section II: Funded Research
(Principal Investigator or Co-Principal Investigator)

Paving the Way to Dynamic Spectrum Sharing: Understanding Spectrum Regulatory and enforcement Mechanics, NSF, $466,485

Advanced Wireless Systems Technologies, NRO, $8,128,864, 8/15/12-1/14/2014

Intelligence Community Center of Academic Excellence, DIA, $1,000,000, 9/23/12 to 9/22/14

Sharing and Shaping of 4G Cellular Resources, AMFI, $369,152, 8/10/12 – 5/9/13

Android Security, ARO, $64,884, 6/1/12 – 5/31/13

SDR Shield: A Hardware-based Security Solution for Software Defined Radio, NSF, $700,000, 9/1/12 – 8/29/18

Next Generation Secure, DARPA (flow through) 10/15/10 – 1/20/13

Outdoor Cognitive Radio Network Test Bed, DoD, 6/15/12 – 6/14/13

Information Assurance of LTE-Advanced, L-3, $30,000, 6/15/12 – 6/14/14

Enhanced Security Monitoring and Intrusion Detection Using Power Fingerprinting and SDR and CR Wireless Systems, Power Fingerprinting Inc., $50,236.00 7/1/2012 – 12/31/2012

Rural Virginia Testbed Planning, CAER, $169,999.00, 1/1/2012 – 9/30/2012

Wireless Assessment of the Gigapark Sites in the Mid Atlantic Broadband Footprint, Mid-Atlantic Broadband. $54,419.00, 7/1/2011 – 9/1/2011

Cognitive Jammer Detection and Classification. Office of Naval Research (ONR), $100,000.00, 10/1/2011 – 9/30/2013

The Android Tactical Application Analysis & Knowledge Cloud, AROSR/ARO

Mobile Cognitive Radio Testbed, ICTAS, $98,291.00, 7/1/2010 – 6/30/2011

Updated to OSSIE Core Framework to Enhance Compatibility with Open CPI, Mercury Federal Systems, $39,998, 7/1/2011 – 12/31/2011

Mobile Cognitive Radio Nodes Testbed, ARO (DURIP II), 5/13/2010 – 5/12/2011, $213,566

Next Generation Secure, Scalable Communication Network for Smart Grid, Oak Ridge National Laboratory, 12/15/2010 – 09/30/2012 $628,671.00

SDR Technology Development Support, Maryland Procurement Office, 9/30/10 – 9/29/2010

$1,562.300 (expected duration 5 years at $5M)

Mobile Cognitive Radio Testbed, ICTAS, 7/1/10 – 6/30/11 $213,566 (co-PI)

Experimental Development Capability for Software Defined Radio with Agile Hardware, ONR, 1/27/2010 – 1/26/2011 $277,718 (co-PI)

Collaborative Research: Enhancing Access to the Radio Spectrum (EARS) Workshop, NSF 4/15/2010 – 03/31/2011 $21,860.00 (co-PI)

Recommendations for Transitioning Silvus MNM FPGA Core IP, DARPA (Silvus Technologies) 2/18/2010 – 2/17/2011, $39,970.00 (co-PI)

NSWC-TO13-Wireless Distributed Computing: Concept to Reality, Naval Secure Warfare (DARPA) Center 8/16/10 – 8/15/2011 - $498.798.0

Investigating the Relationship of OSSIE to Higher Layers, NSF 8/1/2009 – 2/28/10 $76,040

VT-Cornet: Virginia Tech Cognitive Radio Network, ICTAS, 7/1/08 – 6/30/09 $142,580

Cryptographic API and Subsystem Simulator, SCA Technica, 1/1/09 – 9/26/09 $39,000

Cognitive Radio Network Testbed Instrumentation, Office of Naval Research, 4/15/09 – 4/14/10 $347,979

VT-Cognet: Virginia Tech Cognitive Radio Network Testbed Phase 2, ICTAS 1/12/09 – 1/11/10 $149,959 (co-PI)

CT-ISG: Assuring Security in Spectrum Agile Radio Networks, NSF, 01/01/07 - 12/31/10 $499,997 (co-PI).

Improved Distribution and Error Recovery of the OSSIE Core Framework, SAIC 3/01/2009 – 9/30/2009 $75,000

IC CAE: Emerging Technologies IC CAE, Howard University 9/23/2009 – 9/22/2011 $2.5M

REU Supplement to award #0520418 Nets: Oriwub:An Open Systems Approach for Rapid Proto-typing Waveforms for Software Defined Radio, NSF $41,800

Nets Prowin: An Open Systems Approach for Rapid Prototyping Waveforms for Software Defined Radio**,** National Science Foundation, 8/1/08 – 7/31/09 $12,000 (asking for additional REU funding)

Enhancements to OSSIE: (Open Source SCA Implementation: Embedded), Science Applications International Corporation, 4/1/07 – 90/07 $75,000

Collaborative Research: CT-T TRIESTE: A Trusted Radio Infrastructure For Enforcing Spectrum Etiquettes*,* NSF, 10/01/07 – 9/30/10, $150.000 (Reed Co-PI)

Development Design of a Cognitive Engine and Anyalysis of WRAN Cognitive Radio Algorithms, ETRI, 7/01/07 – 12/31/07 $119,999

An Integrated Tool for SCA Waveform Development, Testing, and Debugging and A Tool for Automated Estimation of DSP Resource Statistics for Waveform Components, US-Army-CERDEC Office, 6/12/07 – 6/11/08, $326,125

Software Defined Radio Waveform and Device Development and Component Deployment Using OSSIE, DOD, 7/19/07 – 7/18/10, $975,639 ($184,744 awarded to this point)

Reasoning and Learning in Adapative Wireless Networks, BBN Technologies, 10/1/07 – 12/31/10, $913,196 (co-PI)

US/Ireland International Workshop on Next Generation Open Architectures for Software-Defined Radio, NSF, 9/15/07 – 8/31/08, $35,963

VT-CogNet: Virginia Tech Cognitive Radio Network, ICTAS, 1/1/08 – 6/30/09,$160,170 (Reed, Bose PIs)

Trade Study Of Implementation of SDR: Fundamental Limitations and Future Prospects (DARPA SEED), US Army Aviation & Missile Command, 9/11/07 – 6/30/08 (Reed PI) $115,364

Distributed Computing for Collaborative Software Radio*,* Office of Naval Research, 02/05/07 - 02/04/10, $533,722 ($108,728 awarded first year)

A Panel of Commercial GSM Experts For Supporting JIEDDO Operations, JIEDDO, 12/18/06 - 2/28/07 $38,275

Cognitive Radio Test-bed, Virginia Space Grant Consortium, 08/16/06 - 08/15/07 $5,000

Emerging Wireless Technologies (EWT) Technology Assessment, Rosettex, 07/03/06 - 12/31/07 $91,000

Development of a Cognitive Engine and Analysis of WRAN Cognitive Radio Algorithms, ETRI, 06/16/06 - 12/31/06 $175,554.

Wireless@Virginia Tech Group Start-up, Institute for Critical Technology and Applied Science – ICTAS, 01/01/06 - 06/30/07 $500,000.

A Low-Cost All-Band/All-Mode Radio for Public Safety, National Department of Justice (Dept. of Justice), 10/01/05 - 09/30/08 $399,816 (Reed Co-PI)

Applying Artificial Intelligence Techniques to the Development of a Cognitive Radio Engine: Assessment, Evaluation, and Implementation, Army Research Office, 10/01/05 - 06/30/06 $49,995.

Analysis of WRAN Algorithms, ETRI, 10/01/05 - 12/31/05 $86,275

NeTS PROWIN: An Open System Approach for Rapid Prototyping Waveforms for Software Defined Radios, 08/15/05 - 08/14/09 $999,995 (Reed Co-PI)

Cognitive Radios, Virginia Space Grant Consortium, 08/10/05 - 08/09/06 $5000

A Software Defined Ultra Wideband Communication System Testbed, Virginia Space Grant Consortium, 08/10/05 - 08/09/06 $5,000

Advanced Wireless Integrated Network: AWINN, Office of Naval Research, 12/20/04 - 06/24/06 $484,200 (Reed portion)

Software Defined Radios: Evolution and Application Areas, Booz Allen Hamilton, 1/1/05 - 3/15/05 $74,497

Ossie and Harriet, SAIC, 08/16/04 - 12/31/05 $300,519

CDMA 2000 System Modeling and Simulation Program, Magnolia Broadband, Inc.**,** 12/15/03 - 12/14/04 $84,500

Policy-based Resource Management in a Vehicular Ad-Hoc Network for First Responders, Naval Postgraduate School, 09/24/03 - 09/30/04 $25,431

System Level Design Approach and Methodologies For Software Defined Radios, National Imagery and Mapping Agency, 7/25/03 - 7/24/06 $189,282

Smart Antennas Research At The MPRG, Army Research Office, 06/01/03-12/31/04 $37,500

Proposal for GDDS Cluster X-SCA-Lite Architecture, General Dynamics, 05/01/03-10/31/03 $85,691

Game Theoretic Analysis Of Radio Resource Management For Ad-Hoc Networks**,** Office of Naval Research, 04/01/03-03/31/06 $589,411

Game Theory in Radio Resource Management*,* Motorola University Partnership in Research, 09/01/02 - 05/31/04 $60,000

Software Radios and Smart Antennas: Challenges for Creating Seamless Networks, *Samsung Electronics, 04/08/03 - 05/15/04 $520,785*

UWB Propagation Measurements, Modeling, and Communication System Enhancements, DARPA, 08/16/01 - 12/31/03 $688,620

Tactical Communications Architecture and Implementation Plan for the U.S. Customs Service, Naval Surface Warfare Center, Dahlgren, 8/16/01 - 8/15/02 $402,000

ACN Independent Innovative Research Component, Raytheon Systems, 12/1/01 - 11/30/02 $11,250

Foundation Wireless Network for Medical Applications, Carilion Biomedical Institute, 8/6/01 - 8/10/02 $75,000

Interference, Propagation, and Antenna Placement Issues for XM Radio, GM, 3/26/01 - 9/25/02 $583,527

AOL Fellowship in Wireless Home Networking Technologies, AOL, 01/01/01 - 05/15/03 $84,583

Reconfigurable Apertures and Space-Time Processing, Raytheon Systems, 05/00 - 09/02 $841,350

Advanced Wireless Technology for Aerospace Communications, Virginia Space Grant Consortium, 08/00 - 05/03 $15,000

Research and Development for IMT-2000, LG Electronics, 05/15/00 - 09/31/01 $350,000

Motorola University Partnership in Research: Overloaded Array Processing, Motorola, 09/01/00 - 08/31/02 $84,944

Multiuser Detection for Overloaded Antenna Arrays, Raytheon, 05/00 - 05/02 $1,126,194

An Investigation of Base Station Diversity For Cellular Applications - Phase II, Metawave, 02/29/00 - 02/28/01 $104,000

Broadband Channel-Adaptive Radio Modem for NGI Network Extension and Access, Hughes Research Laboratory, 10/01/99 - 11/30/01 $81,412

Research Into Signal Recovery Algorithms in Support of Spectral Spatial Interference Cancellation System (SSICS) – Phase II Research Effort, Raytheon Company, 02/01/00 - 05/15/01 $149,756

Navy Collaborative Integrated Information Technology Initiative (NAVCIITI), Office of Naval Research, 04/00 - 06/04 $9,651,087 (Reed portion $534,089)

Research into Spatial Signal Recovery Algorithms in Support of Spectral Spatial Interference Cancellation System - Phase I (SSICS), Raytheon Company, 080/2/99 - 01/10/00 $97,857

Low Power and Robust Communications Using Hand-Held Smart Antennas for Receiving and Transmitting, Texas Instruments, 07/01/98 - 06/30/00 $331,993

An Investigation of Base Station Diversity for Cellular Applications, Metawave Communications, 03/01/99 - 02/28/01 $179,706

International Wireless Communication Research Program, Virginia Tech Research and Graduate Studies' SEED Program, 01/01/99 to 06/30/00 $7,500

Navy Collaborative Integrated Information Technology Initiative (NAVCIITI), Office of Naval Research, 11/14/98 - 09/30/00 $2,700,000.

Enhancing the Capacity of IMT-2000 Through Turbo Coding and Smart Antennas, LGIC, 10/01/98 - 09/30/99 $122,904

Low Power and Robust Communications Using Hand-Held Smart Antennas for Receiving and Transmitting, Texas Instruments, 07/01/98 - 06/30/99 $132,000

Techniques for Evaluating Location Technologies, Comcast, 05/01/98 - 12/31/98 $112,154

Development of Tools for CDMA Cellular Network Planning, Innovative Global Solutions (IGS), 04/01/98 - 01/31/99 $42,889

Configurable and Robust Wireless Communications Nodes, DARPA, 07/01/97 - 12/30/00 $2,015,431

Support of Telelink System Test, Global-Net, Inc., 09/25/96 - 09/24/97 $50,000

Sprint RFI and Evaluation, Sprint Spectrum L. P., 09/26/96 - 12/31/96 $31,158

Rural MayDay/800 Call-in System Feasibility, I-95 Corridor Coalition/ Virginia Department of Transportation, 02/01/96 - 01/31/97 $299,176 (MPRG share $157,988)

A Study of Reconfigurable Receivers for Cellular and PCS, Texas Instruments, 08/25/95 - 08/25/96 $35,000

CDMA/FM Evaluation Effort, Comdial Corporation/Sigtek, 08/28/95 - 12/31/95 $25,000 (plus $7,500 CWT match)

Measured DECT System Performance in Actual Radio Channels, National Semiconductor, 10/01/94 - 2/15/96 $35,024

Investigation of BMP Impacts on Nonpoint Source Pollution Using System Analysis Procedures, Virginia Water Resource Center/U.S. Dept. of Interior, 04/01/95 - 04/30/96 $9,963

Development and Implementation Of Interference Rejection Techniques for Cellular Communications, SAIC, Center for Wireless Telecommunications (CWT), $50,000 (SAIC, 03/22/95 to 12/31/95) $25,000 (CWT, 07/01/95 to 06/31/96)

Expanded Testing of a High Capacity Adaptive Wireless Receiver, ARPA/AASERT, 08/01/95 - 07/31/98 $125,522

Co-Channel Interference Rejection for FM Mobile Phone Systems, Motorola, 01/16/95 - 09/15/9, $33,000

Curriculum Innovation for Simulation and Design of Wireless Communications Systems, National Science Foundation, 08/16/95 - 07/31/98 $289,291

A High Capacity Wireless Receiver Implemented with A Reconfigurable Computer Architecture, ARPA/WAMIS, 09/94 - 08/30/97, $1,727,230 ($533,250 for the first year, $586,750 second year)

Development of a Low Power High Data Rate Spread-Spectrum Modem, Grayson Electronics, Virginia's Center for Innovative Technology (CIT), Center for Wireless Telecommunications (CWT), $29,833 (Grayson, 03/01/94 - 11/30/94), $13,204 (CIT, 03/01/94 - 10/31/94) and $16,000 (CWT matching funds, 04/01/94 - 06/30/95)

Rejection of Interference in AMPS Cellular Communication, ARGO Systems, VA's Center for Innovative Technology (CIT), $25,000 (ARGO Systems, 12/10/93 - 05/10/94) and $12,500 (CIT, 04/01/94 - 07/31/94)

Capacity and Interference Resistance of Spread-Spectrum Automatic Vehicle Monitoring Systems in the 902-928 MHz Band, Southwestern Bell Mobile Systems, 10/01/93 - 08/15/94 $70,007

University Road Connection - A Smart Highway, Virginia Dept. of Transportation, 07/01/94 - 11/01/94 $19,523.79

Development of a Spread Spectrum Transceiver for the DECT System, National Semiconductor, 07/01/94 - 06/30/95 $30,000

Investigation of a Dynamic Range Enhancer for an Electro-optic Interface, Southwestern Bell Technology Resources, Inc., 08/01/93 - 06/01/94 $45,000

IVHS Research Center of Excellence, Federal Highway Administration (FHWA), 1993 - 1998, $1 million/year for 5 years (MPRG total approximately $390,000 over performance period, $330,000 received in 93-94, 94-95, 95-96, 96-97 contract years)

Center for Wireless Communications, Center for Innovative Technology, 09/01/93 - 08/31/98, $300,000 for first year. (Anticipated total funding approximately $1,490,835 plus an additional $357,551 of cost sharing by Virginia Tech)

The Performance and Feasibility of Time-Dependent and Non-Linear Adaptive Filters for Rejecting High-Power Co-Located Co-Channel Interference, US Navy via Systems Research Center, 05/15/93 - 09/01/93, Amount: 1/2 summer session support (value approximately $3,750)

Evaluation of an NTP-Based Protocol for Paging and Advanced Data Services, MobileComm, 07/01/93 - 09/30/93 $39,986

Grants & Gifts:

Ted and Karyn Hume center for National Security and Technology Endowment Fund
January 2010, $5,000,000 (Note that most of this money goes for student fellowships, with $200k provided for center support.)
Total Amount - $5,209.010.00

Intel – Jan. 2010, gift for unrestricted research $50,000.00

Tektronix, reconditioned real time spectrum analyzer and two portable analyzers, ~ $130,000

Tektronix - Dec. 2009, reconditioned Arbitrary Function Generator, 100 Mhz, 2 Channel $5,110.00

Wireless@VT Industrial Affiliates Membership 2006-2009:
Affiliate Funding for the year 2009 – 2010 for Dr. Jeffrey H. Reed is $66,960.
Affiliate Funding for the year 2008 - 2009 for Dr. Jeffrey H. Reed is $40,534

Intel Coporation:: 2009 to support the research in “Cognitive Radio for Minimizing Power Consumption” $44,000

Tektronix, 12/2005, cash gift $20,000

Texas Instruments, 08/2005, cash gift $27,519

Tektronix, 07/2005, cash gift $20,000

Texas Instruments. 12/2004, cash gift $99,000

Tektronix, spring 2004, cash gift $20,000

CISCO Systems, 08/2003 and 02/2005, cash gift $176,000

Mercury Computer Systems, Inc., 2003, cash gift $50,000

Analog Devices, 2001-2002, cash gift $37,500

HRL, ***Smart Antenna Research,*** 2000, cash gift $40,000

Rockwell, Flexible Communications Using Reconfigurable Computing, 1998, $25,000 cash gift

Investigation of CDMA, donation from ITT, 1996, cash gift $100,000

MPRG Industrial Affiliates Membership 1993-2006: Grant total split between the five MPRG faculty (total paid $4,866,500 and an additional $110,000 committed to date). Services provided to sponsors include advanced copies of thesis and dissertations, informal consulting, and special opportunities to employ students.

Intel, 10/2007, $40,000, Support research in "Cognitive Radio for Minimizing Power Consumption," 5/2008, $44,000

Texas Instruments, Evaluation Module Kit, 01/2007, $995

Tektronix, Arbitrary Waveform Generator, 02/2007, $138,000.

Xilinx, Inc., Xilinx System Generator, ChipScope Pro, Xilinx Real-PCI interface, AccelDSP Synthesis Tool with AccelWare DSP IP Toolkits, VLYNQ Interface LogiCORE, ISE Foundation, University Option Embedded Development Kit, 01/2007, $39,615

Tektronix, equipment, $114,000

Texas Instruments, 06/2006, $49,500

Mercury Systems, AdapDEV 1280 Chassis with 900 MHz processor, 08/2003

Spectrum Signal Processing, Inc., Hardware necessary to implement a true software defined radio, 08/2002, $62,329

Grayson Wireless, Cellular test and measurement system, 08/2002, $66,312

Signia-IDT (formerly BAE), RF Front-end valve, 2002, ~$6,000

Altera*,* MAX + Plus II Fixed Node Subscription (FPGA board), $2,000

Texas Instruments, Evaluation Module incl. Code Composer Studio, 06/2001, $19,960

Texas Instruments, ADC-Converter, 03/2001, $99

Analog Devices, Evaluation Boards (5), Visual DSP software (2), In-Circuit Emulators (2), $3,790

Wireless Valley Communications, 2 copies SitePlanner w/LanFielder $49,980, 1 copy SiteSpy on SMT $995, 2005, $50,975

Analog Devices, receiver, processor, and receiver chip set, $645

Texas Instruments, boards, 2001, $2,495

HRL, 2000, Diversity Antenna, $200

Altera, development package, 2000, $995

Altera, (2) MAX+ PLUS II Fixed Node Subscription for PC, (1) design lab package, (1) Micro-Chip; $4,765

Motorola, 56311EVM computer board with DSP and 56311 on it, software, documentation, tutorial, and input/output capabilities, 12/2000, $2000

Texas Instruments, Evaluation software and manuals, 1998, $2,500

Texas Instruments, Evaluation Software, 1997, $1,000

Altera, Development Tools for Programming Configurable Logic Devices, $350

Texas Instruments, DSP Development Systems and Software, 1997, $11,475

Texas Instruments, DSP Hardware and Software, 1997, $27,500

Analog Devices, DSP Development Boards, 1996, $3,200

Altera, Software Materials, 1996, $5,000

SIGTEK, Spread Spectrum Receivers, 1995, $10,000

Section III. Teaching & Advising

Classes Taught:

Graduate Courses

Cellular and Personal Communications (ECE6644)
Software Radios: A Modern Approach to Radio Engineering (ECE5674)
Digital Signal Processing (ECE5624)
Cellular (ECE 5664)

Undergraduate Courses

Implementation of Communication Systems (ECE4654)
Signal Processing (ECE4624)
Communication Systems (ECE3604)

Courses Developed:

Major Revision of ECE course 5664 Cellular Radio and Personal Communications to focus on systems level description and design considerations of cellular standards this will take two more years to complete and result in a textbook.
Implementation of Communication Systems (ECE 4654)
Developed Class in Software Radio (ECE 5664)

Advising: Completed Ph.D. Dissertations:

Yash Vasavada, “An Iterative Confidence Passing Approach for Parameter Estimation and Its Applications to MIMO Systems,” May, 2012

Hazem Shatila, “Adaptive Radio Resource Management in Cognitive Radio Communications Using Fuzzy Logic,” April 2012

Ashwin Amanna, “Statistical Experimental Design Framework for Cognitive Radio,” March 19, 2012

Carlos Aguayo Gonzales, “Power Fingerprinting for Integrity Assessment of Embedded Systems,” December 5, 2011

Xueato Chen, “Resource Allocation for Wireless Distributed Computing Networks,” (Co-Advised with Dr. Tamal Bose) completed May 2012

An He, “ Power Consumption Optimization – A Cognitive Radio Approach,” February 2011

Joseph Gaeddert, “Facilitating Wireless Communications through Intelligent Resource Management on Software-Defined Radios in Dynamic Spectrum Environments,” January 2011

Lizdabel Moarles Tirando, “An Approach to Using Cognitive in Wireless Networks,” December 2009

Kyou Woong Kim, “Exploiting cyclostationarity for radio environmental awareness in cognitive radios,” May 2008

Youping Zhao, “Enabling cognitive radios through radio environment maps,” May 2007

Rekha Menon, “Interference avoidance based underlay techniques for dynamic spectrum sharing,” April 2007 (co-advised with Dr. Michael Buehrer)

Jong-Han Kim, “On the impact of MIMO implementations on cellular networks: An analytical approach from a system perspective,” March 2007

Ramesh Chembil Palat, “Performance analysis of cooperative communications for wireless networks,” December 2006

Jody Neel, "Analysis and design of cognitive radio networks and distributed radio resource management algorithms," September 2006

Chris Anderson, "A software defined ultra wideband transceiver testbed for communications, ranging, or imaging." September 2006

James Hicks, "Novel approaches to overloaded array processing," August 2003

Raqibul Mostafa, "Feasibility of smart antennas for the small wireless terminals," April 2003

William Newhall, "Radio channel measurements and modeling for smart antenna array systems using a software radio receiver," April 2003

Pablo Max Robert, "Reduction in coexistent WLAN interference through statistical traffic management," April 2003

Tom Biedka, "Analysis and development of blind adaptive beamforming algorithms," August 2001

Srikathyayani Srikanteswara, "Design and implementation of a soft radio architecture for reconfigurable platforms," July 2001

Rich Ertel, "Antenna array systems: Propagation and performance," July 1999

Nitin Mangalvedhe, "Development and analysis of adaptive interference rejection techniques for direct sequence code division multiple access systems," July 1999

Nishith Tripathi, "Generic handoff algorithms using fuzzy logic and neural networks," November 1997

Paul Petrus, "Novel adaptive array algorithms and their impact on cellular system capacity," April 1997

Jeff Laster, "Robust GMSK demodulation using demodulator diversity and BER estimation," January 1997

Rong He, "AMPS co-channel interference rejection techniques and their impact on system capacity, August 1996

Completed M.S. Theses:

Scott Meuleners, "Design and Implementation of a Distributed TDOA-Based Geolocation System using OSSIE and Low Cost USRP Boards," May 2012

Thomas Cooper, " Integration of Open-Source Networks," May, 2012

Shawn Hymel, "Massively Parallel Hidden Markov Models for Wireless Applications," December 5, 2011

Peter Sahmel, "Eigenspace Approach to Specific Emitter Identification of Orthogonal Frequency Division Multiplexing Signals," Nov. 2011

Hermie Mendoza, “Distributed Localization for Wireless Distributed Networks in Indoor Environments,” June, 28, 2011

Soumava Bera, “Design and Implementation of a MAC Protocol for Wireless Distributed Computing,” June 11

Hermie Mendoza, “Distributed Localization for Wireless Distributed Networks in Indoor Environments,” May 2011

Matthew Price , “Automatic Modulation Classification Using Grey Relational Analysis,,” April 2011

Ben Hilburn, “Component-Based Design and Service-Oriented Architectures in Software-Defined Radio,” April 2011

Sabares S. Moola, “Rapid Prototyping of Software Defined Radios using Model Based Design for FPGAs,” on July 22, 2010
Nikhil Challa, “ Approaches for Optimizing Software Defined Radio Performance,” on January 31, 2011

Ishtiaq Rouf, “Statistical Analysis of Wireless Communication Systems Using Hidden Markov Models,” July 2009

Matthew Carrick, “Logical representation of FPGA’s & FPGA circuits within the SCA,” July 2009

Patrick Farrell, “Digital hardware designing decisions & trade-offs for software radio systems,” May 2009

Philip Balister, “A software defined radio implemented using the OSSIE core framework deployed on a TI OMAP processor.” December 2008

Jacob DePriest, “A practical approach to rapid prototyping of SCA waveforms,” April 2006

Srinivasan Vasudevan, ”A simulation for analyzing the throughput of IEEE 802.11b wireless LAN systems,” January 2005

Brian Donlan, “Ultra-wideband narrowband interference cancellation and channel modeling for communications,” January 2005

Anil Hebbar, “Empirical approach for rate selection in MIMO OFDM,” December 2004

Seshagiri Krishnamoorthy, “Interference measurements and throughput analysis for 2.4 GHz wireless devices in hospital environments,” April 2003

Yasir Ahmed, “A model-based approach to demodulation of co-channel MSK signals,” December 2002

Ramesh Chembil Palat, “VT-Star – Design and implementation of a test bed for differential space-time block coding and MIMO channel measurements,” October 2002

Jody Neel, “Simulation of an implementation and evaluation of the layered radio architecture,” December 2002

Bing-Leung (Patrick) Cheung, “Simulation of adaptive algorithms for OFDM and adaptive vector OFDM systems,” August 2002

Shakheela H. Marikar, “Resource management in 3G systems employing smart antennas, January 2002

M. Soni, “Computing engine for reconfigurable software radio,” Oct. 2001

Christian Rieser, “Channel sounder for LMDS,” May 2001 (co-advisor)

James Hicks, “Overloaded array processing with spatially reduced search joint detection,” May 2000

Zhong Hu, “Evaluation of joint AOA and DOA estimation algorithms using the antenna array systems,” May 1999

Kim Phillips, “Probability density function estimation for minimum bit error rate equalization,” May 1999

Pablo (Max) Robert, “Simulation tool and metric for evaluating wireless digital video systems,” May 1999

Steven F. Swanchara, “An FPGA-based multiuser receiver employing parallel interference cancellation,” July 1998

Don Breslin, “Adaptive antenna arrays applied to position location,” August 1997

Steve Nicoloso, “Investigation of carrier recovery techniques for PSK modulated signals in CDMA and multipath mobile environments,” May 1997

Brian Fox, “Analysis and dynamic range enhancement of the analog-to-digital interface in multimode radio receivers,” February 1997

Nena Zecevic, “Interference rejection techniques for the mobile unit direct-sequence CDMA receiver, August 1996

Kevin Saldanha, “Performance evaluation of DECT in different radio environments,” August 1996

Milap Majmundar, “Adaptive single-user receivers for direct sequence CDMA systems,” February 1996

Yash Vasavada, “Performance evaluation of a frequency modulated spread spectrum system,” February 1996

Scott Elson, “Simulation and performance analysis of CDPD,” January 1996

Matthew Welborn, “Co-channel interference rejection using model-based demodulator,” January 1996

Francis Dominique, "Design and development of a frequency hopper based on the detection system for the 902-928 MHz ISM band," December 1995

Nitin Mangalvedhe, "An Eigenstructure technique for direct sequence spread spectrum synchronization," April 1995

Paul Petrus, "Blind adaptive arrays for mobile communications," December 1994

Sihano (Raymond) Zheng, "Channel modeling and interference rejection for CDMA automatic vehicle monitoring systems," November 1994

Fu-Sheng (Frank) Cheng, "A new approach to dynamic range enhancement," September 1994

Volker Aue, "Optimum linear single user detection in direct-sequence spread-spectrum multiple access systems," March 1994

Current Ph. D Students:

Eyosias Iman – Ph.D expected completion date December 2013

Dinesh Datla – Ph.D expected completion date July 2012

Karim Said – Ph.D expected completion date May

Abid Ullah – Ph.D expected completion date December 2013

Shravan Garlapati – Ph.D expected completion date May 2013

Matthew Vondall – Ph. D (Co-Advised with Amir Zaghoul) expected completion date Spring, 2013

Stephen Dudley – Ph.D expected completion date May 2014

Matthew Carrick – Ph.D. expected completion date May 2015

Current M.S. Students:

Karim Said - M.S expected completion date June 2012

Thomas Tsou – M.S. expected completion date June 2012

Michael Benonis – M.S. expected completion date December 2012

Sumedha Mohan – M.S. expected completion date May 2013

Section IV. Publications List

Books Authored or Co-Authored:

1. J. H. Reed, ed., An Introduction to Ultrawideband Communications Systems, Prentice Hall, March 2005, ISBN: 0-13-148103-7.

2. J. H. Reed, Software Radio: A Modern Approach to Radio Design, Prentice Hall, May 2002, ISBN: 0-13-081158-0.

3. N. D. Tripathi, J. H. Reed, and H. F. VanLandingham, Radio Resource Management in Cellular Systems, Kluwer Academic Publishers, Spring 2001.

Books & Proceedings Edited:

1. W. H. Tranter, B. D. Woerner, J. H. Reed, T. S. Rappaport, and P. M. Robert, Wireless Personal Communications – Bluetooth and Other Technologies, Kluwer Academic Publishers, 2000.

2. W. H. Tranter, B. D. Woerner, T. S. Rappaport, and J. H. Reed, Wireless Personal Communications – Channel Modeling and Systems Engineering, Kluwer Academic Publishers, 1999s.

3. W. H. Tranter, T. S. Rappaport, B. D. Woerner, and J. H. Reed, eds., Wireless Personal Communications: Emerging Technologies for Enhanced Communications, Kluwer Press, 1998.

4. T. S. Rappaport, B. D. Woerner, J. H. Reed, and W. H. Tranter, eds., Wireless Personal Communications: Improving Capacity, Services, and Reliability, Kluwer Press, 1997.

5. J. H. Reed, B. D. Woerner, and T. S. Rappaport, eds., Wireless Personal Communications: Advances in Coverage and Capacity, Kluwer Press, 1997.

6. T. S. Rappaport, B. D. Woerner, and J. H. Reed, eds., Wireless Personal Communications: The Evolution of PCS, Kluwer Press, 1996.

7. B. D. Woerner, T. S. Rappaport, and J. H. Reed, eds., Wireless Personal Communications: Research Developments, Kluwer Press, 1995.

8. T. S. Rappaport, B. D. Woerner, and J. H. Reed, editors, Wireless Personal Communications: Trends and Challenges, Kluwer Press, 1994.

Book Contributions:

1. H. I. Volos, D. Datla, X. Chen, A. He, A. Amanna, T. R. Newman, S.M. Shajedul Hasan, J. H. Reed, and T. Bose, "Green Communications: Realizing Environmentally Friendly, Cost Effective, and Energy Efficient Wireless Systems," in Energy-Aware Systems and Networking for Sustainable Initiatives, IGI Global, June 2012

2. A. He, A. Amanna, X. Chen, D. Datla, J. Gaeddert, S.M. Hasan, H. Volos, “Sustainable Green Computing: Practices, Methodologies and Technologies,” edited by Dr. Wen-Chen Hu and Dr. Naima Kaabouch, University of North Dakota, USA IGI Global, 2012

3. “Technical Challenges in Applying Network Neutrality Regulations to Wireless Systems,” “Net Neutrality: Contributions to the Debate,” Nishith D. Tripathi and Jeffrey H. Reed, Edited by Jorge Perez Martinez, 2011

4. “The Radio Environment Map”, (Book Chapter) Cognitive Radio Technology, Dr. Bruce Fette, ed., Y. Zhao, S. Mao, J. Neel, and J.H. Reed2nd edition, 2 April 2009

5. J. Neel. J. Reed, A. MacKenzie, Cognitive Radio Network Performance Analysis in Cognitive Radio Technology, B. Fette, ed., Elsevier, 2nd edition, 2 April 2009.

6. Y. Zhao, S. Mao, J. Neel, and J. H. Reed, “The Radio Environment Map” (Book Chapter) in Cognitive Radio Technology, B. Fette, ed., 2nd ed., Elsevier, April 2009.

7. J. Neel. J. Reed, and A. MacKenzie, “Cognitive Radio Network Performance Analysis” (Book Chapter) in Cognitive Radio Technology, B. Fette, ed., 2nd ed., Elsevier Inc., April 2009.

8. Y. Zhao, B. Le, and J. H. Reed, “Network Support: The Radio Environment Map” (Book Chapter) in *Cognitive Radio Technology*, by B. Fette, Elesvier Inc., pp. 337-363, August 2006, ISBN: 978-0-7506-7952-7.

9. J. O. Neel, J. H. Reed, and A. B. MacKenzie, “Cognitive Radio Performance Analysis” (Book Chapter) in *Cognitive Radio Technology*, by B. Fette, Elesvier Inc., pp. 501-579, August 2006, ISBN: 978-0-7506-7952-7.

10. B. M. Donlan, R. M. Buehrer, and J. H. Reed, “Ultra-wideband Wireless Systems,” in the *Encyclopedia of RF and Microwave Engineering*, pp. 5411-5423, Spring 2005, ISBN: 0-471-27053-9.

11. N. D. Tripathi, J. H. Reed, and H. F. VanLandingham, “Application of a Neurofuzzy System to Handoffs in Cellular Communications” (Book Chapter) in *Neuro-Fuzzy and Fuzzy-Neural Applications in Telecommunications (Signals and Communication Technology)*, by P. Stavroulakis, Springer Publishing, May 2004, ISBN: 3540407596.

12. J. H. Reed and C. J. Rieser, “Software Radio: Technical, Business and Market Implications,” in *World Market Series Business Briefing Wireless Technology 2001,* WMRC *PLC – World Markets Research Centre*, pp. 146-150, October 2000, ISBN 1-903140-36-1.

13. P. Petrus and J. H. Reed, “Co-channel Interference in Wireless Communication Systems,” in *Encyclopedia of Electrical and Electronics Engineering*, John Wiley & Sons, Inc., February 1999 (invited paper).

14. N. R. Mangalvedhe and J. H. Reed, “Analysis of an Eigenstructure Technique for DSSS Synchronization,” in *Wireless Personal Communications: The Evolution of PCS*, Kluwer Press, 1996 (also appears in *Virginia Tech’s Sixth Annual Symposium on Wireless Personal Communications*, June 1996), pp. 201-214.

15. J. D. Laster and J. H. Reed, “A Survey of Adaptive Single Channel Interference Rejection Techniques for Wireless Communications,” in *Wireless Personal Communications:*

Research Developments, Kluwer Press, 1995 (also appears in *Virginia Tech's Fourth Annual Symposium on Wireless Personal Communications*, June 1994), pp.29-54.

16. I. Howitt, J. H. Reed, V. Vemuri, and T. C. Hsia, "Recent Developments In Applying Neural Nets to Equalization And Interference Rejection," in *Wireless Personal Communications: Trends and Challenges*, Kluwer Press, 1994 (also appears in *Virginia Tech's Third Symposium on Wireless Personal Communications*, June 1993), pp.49-58.

Papers in Refereed Journals:

1. Raqibul Mostafa, Ramesh C. Pallat, Uwe Ringel, Ashok Arman Tikku, and Jeffrey H. Reed, Closed-Loop Transmit Diversity Techniques for Small Wireless Terminals and Their Performance Assessment in a Flat Fading Channel, ETRI Journal, vol.34, no.3, June 2012, pp.319-329.

2. Reed, J. H.; Bernhard, J. T.; Park, J.-M. "Spectrum Access Technologies: The Past, the Present, and the Future," Proceedings of the IEEE , vol.100, no. Special Centennial Issue, pp.1676-1684, May 2012, (invited paper)

3. Ashwin E Amanna, Daniel Ali, Manik Gadhiok, Matthew Price and Jeffrey H Reed, "Cognitive radio engine parametric optimization utilizing Taguchi analysis," EURASIP Journal on Wireless Communications and Networking 2012, 2012:5

4. Xuetao Chen, Tamal Bose, S.M. Hasan and Jeffrey H. Reed, "Efficient detection of primary users in cognitive radio networks," Journal International Journal of Communication Networks and Distributed Systems, Publisher Interscience Enterprises Ltd, Issue Volume 8, Number 3–4/2012, Pages 267-285.

5. Shatila, H., Khedr, M. and Reed, J. H., Opportunistic channel allocation decision making in cognitive radio communications. Int. J. Commun. Syst.. April 2012. DOI: 10.1002/dac.2350

6. Datla, D.; Chen, X.; Tsou, T.; Raghunandan, S.; Hasan, S.M.S.; Reed, J.H.; Dietrich, C.B.; Bose, T.; Fette, B.; Kim, J.; , "Wireless distributed computing: a survey of research challenges," Communications Magazine, IEEE , vol.50, no.1, pp.144-152, January 2012

7. T. Yang, W. Davis, W. Stutzman, J. Nealy, D. Dietrich, S.M. Hasan, J.H. Reed, "Antenna Design Strategy and Demonstration for Software-Defined Radio (SDR)," Analog Integrated Circuits and Signal Processing: Volume 69, Issue 2 (2011), Page 161-171 (update paper from SDR'10 conference)

8. Harpreet S. Dhillon, Jeong-O Jeong, Dinesh Datla, Michael Benonis, R. Michael Buehrer and Jeffrey H. Reed, "A sub-space method to detect multiple wireless microphone signals in TV band white space," Analog Integrated Circuits and Signal Processing, Springer Netherlands, December 2011, Volume 69, Issue 2, pp. 297-306. (update paper from SDR'10 conference)

9. Carlos R. Aguayo González and Jeffrey H. Reed, "Power fingerprinting in SDR integrity assessment for security and regulatory compliance," Analog Integrated Circuits and Signal Processing, Volume 69, Numbers 2-3 (2011), 307-327. (update paper from SDR'10 conference)

10. Dinesh Datla, Haris I. Volos, S. M. Hasan, Jeffrey H. Reed and Tamal Bose, “Task allocation and scheduling in wireless distributed computing networks,” Analog Integrated Circuits and Signal Processing , Volume 69, Numbers 2-3 (2011), 341-353. (update paper from SDR’10 conference)

11. Amanna, K. Thamvichai, M. Carrick, AT. Bose, J. Reed, “Grey Systems Theory Applications to Wireless Communications,” Analog Integrated Circuits and Signal Processing: Volum 69, Issue 2 (2011), Page 259 (update paper from SDR’10 conference)

12. An He, Ashwin Amanna, Thomas Tsou, Xuetao Chen, Dinesh Datla, Joseph Gaeddert, Timothy R Newman, Shajedul Hasan, Haris I Volos, Jeffery H Reed, Tamal Bose, “Green Communications: A Call for Power Efficient Wireless Systems,” Journal of Communications, Vol 6, No 4 (2011), 340-351, Jul 2011

13. A. He, A. Amanna, T. Tsou, X. Chen. D. Datla, J. Gaeddert, T. Newman, S.M. Hasan, H. Volos, J.H. Reed, T. Bose, “Green Communications: A New Paradigm for Power Efficient Wireless Systems,” Journal of Communications Special Issue on Practical Physical Layer Techniques for 4G Systems & Beyond, Vol 6, No. 5. July 2011.

14. D. Datla, H.I. Volos, S.M. Hasan, Jeffrey H. Reed and Tamal Bose, “Wireless Distributed Computing in Cognitive Radio Networks, Ad-Hoc Network (Elsevier,” available online April 15, 2011. (Print copy to be issued)

15. T. Newman, S.M. Hasan, D.Depoy, T. Bose, J.H.Reed, “Designing and Deploying a Building-Wide Cognitive Radio Network Testbed,” *IEEE Communications Magazine,* September 2010

16. A. He, S. Srikantesware, K.K. Bae, T.R. Newman, W. Tranter, M. Verhelst, J. Reed, "Power Consumption Minimization for MIMO Systems- A Cognitive Radio Approach," IEEE JSAC September 2010.

17. A. Amanna, M. Ghadiok, M. Price, J.H. Reed, "Railway Cognitive Radio," IEEE Vehicular Technology Magazine, September 2010, Volume 5, Issue 3, pages 82-89.

18. A. He, S. Srikanteswara, K. K. Bae, J. H. Reed, and W. H. Tranter, "Energy consumption minimization for mobile and wireless devices - a cognitive approach," IEEE Transactions on Consumer Electronics, vol. 56, no. 3, Aug. 2010.

19. A.R. Cormier, Carl B. Dietrich, Jeremy Price, and Jeffrey H. Reed, "Dynamic reconfiguration of software defined radios using standard architectures," Physical Communication, vol. 3, no. 2, June 2010, Pages 73-80 ,doi:10.1016/j.phycom.2009.09.002

20. An He, Kyung Kyoon Bae, T.R. Newman, J. Gaeddert, K. Kim, R. Menon, L. Morales, J. Neel, Y Zhao, J.H. Reed, W.H. Tranter, ”A Survey of Artificial Intelligence for Cognitive Radios”, IEEE Transactions on Vehicular Technology, vol. 59, no. 4, May 2010, pp. 1578-1592.

21. Donglin Hu, Shiwen Mao, Y. Thomas Hou, and Jeffrey H. Reed, "Fine grained scalability video multicast in cognitive radio networks," IEEE Journal on Selected Areas in Communications, Special Issue on Wireless Video Transmission, vol.28, no.3, pp.334--344, April 2010.

22. Carl B. Dietrich, Jeffrey H. Reed, Stephen H. Edwards, Frank E. Kragh, "Experiences From the OSSIE Open Source Software Defined Radio Project," Open Source Business Resource, March, 2010.

23. Menon, R. Macke, A Buehrer M., Reed, J.H. "Interference Avoidance in Networks with Distributed Receivers", IEEE Transactions on Wireless Communications, Vo.57, Issue 10, October 2009, pp. 3078-3091.

24. C. R. Anderson, S. Venkatesh, J. Ibrahim, R. M. Buehrer, and J. H. Reed, "Performance and analysis of a time-interleaved ADC array for a software-defined UWB receiver," Oct. 2009, Volume: 58, Issue: 8, pp. 4046-4063

25. C. R. Aguayo Gonzalez, C. B. Dietrich, F. E. Kragh, S. Sayed, H. I. Volos, J. D. Gaeddert, P. M. Robert, and J. H. Reed, "Open-source SCA-based core framework and rapid development tools enable software-defined radio education and research," *IEEE Commun. Mag.*, October 2009.

26. C. R. Aguayo Gonzalez, C. B. Dietrich, and J. H. Reed, "Understanding the software communications architecture," *IEEE Commun. Mag.*, vol. 47, no. 9, September 2009.

27. Y. Zhao, S. Mao, J.H. Reed, Y Huang, " Utility Function Selection for Streaming Videos with a Cognitive Engine Test Bed", ACM/Springer Mobile Networks and Applications (MONET) at SpringerLink, August 18, 2009.

28. An He, Joseph Gaeddert, Kyung Kyoon Bae, Timothy R. Newman, Jeffrey H. Reed, R. Chembil Palat, A. Annamalai, and J. H. Reed, "Accurate bit error rate analysis of bandlimited cooperative OSTBC networks under time synchronization errors," *IEEE Trans. Veh. Technol.*, vol. 58, no. 5, pp. 2191-2200, June 2009.

29. S. Haykin, D.J. Thomson, J.H. Reed, "Spectrum Sensing for Cognitive Radio," *Proceedings of the IEEE,* Vol. 97, Issue 5, May 2009, pp. 849-877.

30. R. Menon, A. B. MacKenzie, J. Hicks, R. M. Buehrer, and J. H. Reed, "A game-theoretic framework for interference avoidance," *IEEE Trans. Commun.*, vol. 57, no. 4, pp. 1087-1098, April 2009.

31. An He, J. Gaeddert, K. Bae, T. Newman, J. Reed, I. Morales, and C. H. Park, "Development of a case-based reasoning cognitive engine for IEEE 802.22 WRAN Applications," *ACM SIGMOBILE Special Issue on Cognitive Radio Technologies and Systems*, vol. 13, no. 2, pp. 37-48, April 2009.

32. Lizdabel Morales, Chang-Hyun Park, "Development of a Case-Based Reasoning Cognitive Engine for IEEE 802.22 WRAN Applications," ACM Sigmobile Mobile Computing and Communications Review, vol. 13, no.2, pp. 37-48, April 2009.

33. A. B. Mackenzie, J. H. Reed, P. Athanas, C. W. Bostian, R. M. Buehrer, L. A. DaSilve, S. W. Ellingson, Y. T. Hou, M. Hsiao, J. M. Park, C. Patterson, S. Raman, and C. R. C. M. da Silva, "Cognitive radio and networking research at Virginia Tech," *Proceedings of the IEEE*, vol. 97,no. 4, pp. 660-688, April 2009.

34. Y. Zhao, S. Mao, J. O. Neel, and J. H. Reed, “Performance Evaluation of cognitive radios: Metrics, utility functions, and methodology,” *Proceedings of the IEEE*, vol. 97, no. 4, pp. 642-659, April 2009.

35. Seung Min Hur, Shiwen Mao, Y. Thomas Hou, Kwanghee Nam, and Jeffrey H. Reed, "On exploiting location information for concurrent transmission in multi-hop wireless networks," *IEEE Transactions on Vehicular Technology*, vol.58, no.1, pp.314-323, January 2009.

36. R. Menon, R. M. Buehrer, and J. H. Reed, “On the impact of dynamic spectrum sharing techniques on legacy radio systems,” *IEEE Trans. Wireless Commun.*, vol. 7, no. 11, part 1, pp. 4198-4207, November 2008.

37. D.-K. Park, T. Saba, and J. H. Reed, “Technical Standard for unlicensed radio device on DTB band in U.S.A.,” *IEICE Trans. Commun.*, (Japanese Edition), vol. J91-B, no. 11, pp. 1351-1358, November 2008.

38. R. Chen, J.-M. Park, Y. T. Hou, and J. H. Reed, “Toward secure distributed spectrum sensing in cognitive radio networks” (cognitive radio communication and networks), *IEEE J. Select. Areas Commun.*, vol. 46, no. 4, pp. 50-55, April 2008.

39. R. C. Patat, A. Annamalai, and J. H. Reed, “An efficient method for evaluation information outage probability and ergodic capacity of OSTBC systems,” *IEEE Commun. Lett.*, vol. 12, no. 3, pp. 191-193, March 2008.

40. R. Chen, J.-M. Park, and J. H. Reed, “Defense against primary user emulation attacks in cognitive radio networks,” *IEEE J. Select. Areas Commun.*, vol. 16, no. 1, pp. 25-37, January 2008.

41. S. Mao, X. Cheng, Y. T. Hou, H. D. Sherali, and J. H. Reed, “On joint routing and server selection for MD video streaming in ad hoc networks,” *IEEE Trans. Wireless Commun.*, vol. 6, no. 1, pp. 338-347, January 2007.

42. C. A. Gonzalez, F. Portelinha, and J. H. Reed, “Design and implementation of an SCA core framework for a DSP platform,” part 1, *Military Embedded Systems Mag.*, March/April 2007 issue. Part 2 in May/June 2007 issue.

43. J. O. Neal, R. Menon, A. B. MacKenzie, J. H. Reed, and R. P. Gilles, “Interference reducing networks,” *MONET Special Issue - Cognitive Radio Oriented Wireless Networks Commun.*, February 2007.

44. N. Ryu, Y. Yun, S. W. Choi, R. Chembil Palat, and J. H. Reed, “Smart antenna base station open Architecture for SDR networks,” *IEEE Trans. Wireless Commun.*, vol. 13, no. 3, pp. 58-69, June 2006.

45. L. daSilva, G. E. Morgan, C. W. Bostian, S. F. Midkiff, J. H. Reed, C. Thompson, W. G. Newhall, and B. D. Woerner, “The resurgence of push-to-talk technologies,” *IEEE Commun. Mag.*, vol. 44, no. 2, pp. 48-55, January 2006.

46. V. Srivastava, J. Neel, A. Mackenzie, J. Hicks, L. DaSilva, J. H. Reed, and R. P. Gilles, “Using game theory to analyze wireless ad hoc networks,” *IEEE Commun. Surveys Tutorials,* pp. 46-56, December 2005.

47. B. Le, T. W. Rondeau, J. H. Reed, and C. W. Bostian, “Analog-to-digital Converters,” *IEEE Signal Processing Mag.*, pp. 69-77, November 2005.

48. R. Mostafa, R. Gozali, P. M. Robert, R. Chembil Palat, B. D. Woerner, and J. H. Reed, “Design and implementation of a DSP-based MIMO system prototype for real-time demonstration and indoor channel measurements,” *Eurasip J. Applied Signal Processing*, vol. 2005, no. 16, pp. 2673-2685, September 2005.

49. R. Mostafa, A. Annamalai, and J. H. Reed, “Performance evaluation of cellular mobile radio systems with adaptive interference nulling of dominant interferers,” *IEEE Trans. Commun.*, vol. 52, no. 2, pp. 326-335, February 2004.

50. S. Srikanteswara, R. Chembil Palat, J. H. Reed, and P. Athanas, “Overview of configurable Computing machines for software radio handsets,” *IEEE Commun. Mag,*, pp. 134-141, July 2003.

51. J. D. Laster, J. H. Reed, and W. H. Tranter, “Bit error rate estimation using probability density function estimators,” *IEEE Trans. Veh. Technol.*, vVol. 52, no. 1, pp. 260-267, January 2003.

52. P. Petrus, J. H. Reed, and T. S. Rappaport, “Geometrical-based statistical macrocell channel model for mobile environments,” *IEEE Trans. Commun.*, vol. 50, no. 3, pp. 495-502, March 2002.

53. R. Mostafa, F. Alam, K. K. Bae, J. H. Reed, W. H. Tranter, and B. D. Woerner, “3G-around the world and back again,” *RF Design*, February 2002.

54. J. Hicks, S. Bayram, W. H. Tranter, R. J. Boyle, and J. H. Reed, “Overloaded array processing with spatially reduced search joint eetection,” *IEEE J. Select. Areas Commun.*, vol. 19, no. 8, pp. 1584-1593, August 2001.

55. T. Li, Y. M. Vasavada, B. D. Woerner, and J. H. Reed, “A novel direct sequence spread spectrum CDMA system with analog frequency modulation,” *International J. Wireless Inform. Networks*, vol. 7, no.1, pp. 43-53, 2000.

56. M. Majmundar, N. Sandhu, and J. H. Reed, “Adaptive single-user receivers for direct-sequence spread-spectrum CDMA systems,” *IEEE Trans. Veh. Technol.,* vol. 49, no. 2, pp. 379-389, March 2000.

57. T. E. Biedka, W. H. Tranter, and J. H. Reed, “Convergence analysis of the least squares constant modulus algorithm in interference cancellation applications,” *IEEE Trans. Commun.*, vol. 48, no. 3, pp. 491-501, March 2000.

58. S. Srikanteswara, J. H. Reed, P. Athanas, and R. Boyle, “A soft radio architecture for reconfigurable platforms,” *IEEE Commun. Mag.,* pp. 140-147, February 2000.

59. R. B. Ertel and J. H. Reed, "Angle and time of arrival Statistics for circular and elliptical scattering models," *IEEE J. Select. Areas Commun., Wireless Commun. Series*, vol. 17, no. 11, pp. 1829-1840, November 1999.

60. N. Tripathi and J. H. Reed, “Handoffs in cellular systems,” *IEEE Pers. Commun.*, pp. 26-37, December 1998.

61. R. B. Ertel and J. H. Reed, "Generation of two equal power correlated Rayleigh fading envelopes," *IEEE Commun. Lett.*, vol. 2, no. 10, pp. 276-278, October 1998.

62. P. J. Athanas, J. H. Reed, and W. H. Tranter, "A prototype software radio based on configurable computing," *Advancing Microelectronics, Special Wireless Issue*, vol. 5, no. 3, pp. 33-38, 1998. (invited paper)

63. J. H. Reed, K. J. Krizman, B. D. Woerner, and T. S. Rappaport, "An overview of the challenges and progress in meeting the E911 requirement for location service," *IEEE Commun. Mag.*, pp. 30-37, April 1998.

64. P. Petrus, R. B. Ertel, and J. H. Reed, "Capacity enhancement using adaptive arrays in an AMPS system," *IEEE Trans. Veh. Technol.*, vol. 47, no. 3, pp. 717-727, August 1998.

65. P. Petrus, J. H. Reed, and T. S. Rappaport, "Geometrically based statistical macrocell channel model for mobile environments," *IEEE Trans. Commun.*, accepted for publication.

66. R. B. Ertel, P. Cardieri, K. W. Sowerby, T. S. Rappaport, and J. H. Reed, "Overview of spatial channel models for antenna array communication systems," *IEEE Pers. Commun.*, pp. 10-22, February 1998. (Also appears in *IEEE Smart Antennas: Adaptive Arrays, Algorithms, Wireless Position Location*, pp. 447-456, 1998.)

67. P. Petrus and J. H. Reed, "Performance analysis of the spectral correlation discriminator array," *International J. Wireless Pers. Commun. Special Issue*, pp. 337-359, February 1998.

68. Z. Rong, P. Petrus, T. S. Rappaport, and J. H. Reed, "Despread-respread multi-target constant modulus array for CDMA systems," *IEEE Commun. Lett.*, pp. 114-116, July, 1997.

69. J. Laster and J. H. Reed, "Interference rejection in digital wireless communications," *IEEE Signal Processing Mag.*, pp. 37-62, May, 1997.

70. P. Petrus, J. H. Reed, and T. S. Rappaport, "Effects of directional antennas at the base station on the doppler spectrum," *IEEE Commun. Lett.*, pp. 40-42, March 1997. (Also appears in *IEEE Smart Antennas: Adaptive Arrays, Algorithms, Wireless Position Location*, pp. 489-491, 1998.)

71. F. Dominique, J. H. Reed, "Subspace based PN code sequence estimation for direct sequence signals simplified Hebb rule," *IEEE Electron. Lett.*, vol. 33, pp. 1119-1120, June 1997.

72. F. Dominique and J. H. Reed, "Estimating spectral correlations using the least mean square algorithm," *IEE Electron. Lett.*, pp. 182-184, January 1997.

73. F. Dominique and J. H. Reed, "A despread data rate update multi-target adaptive array for CDMA signals," *IEE Electron. Lett.*, pp. 119-121, January 1997.

74. F. Dominique and J. H. Reed, "A simple PN code sequence estimation and synchronization techniques using the constrained Hebbian rule," *IEE Lett.*, pp. 37-38, January 1997.

75. B. G. Agee, R. J. Kleinman, and J. H. Reed, "Soft synchronization of direct sequence spread spectrum signals," *IEEE Trans. Commun.*, pp. 1527-1536, November, 1996.

76. T. S. Rappaport, J. H. Reed, and B. D. Woerner, "Position location using wireless communications on highways of the future," *IEEE Commun. Mag.*, vol. 34, no. 10, pp. 33-41, October 1996. (invited paper) (Also appears in *IEEE Smart Antennas: Adaptive Arrays, Algorithms, Wireless Position Location*, pp. 393-401, 1998.)

77. N. Mangalvedhe and J. H. Reed, "Evaluation of a soft synchronization technique for DS/SS signals," *IEEE J. Select. Areas Commun.*, vol. 14, no. 8, pp. 1643-1652, October 1996.

78. F. Dominique and J. H. Reed, "A robust frequency hop synchronization algorithm," *IEE Electron. Lett.*, vol. 32, no. 16, pp. 1450-1451, August 1996.

79. P. Petrus and J. H. Reed, "Time dependent adaptive arrays," *IEEE Signal Processing Lett.*, vol. 2, no. 12, pp. 219-222, December 1995.

80. J. H. Reed, N. Yuen, and T. C. Hsia, "An optimal receiver implemented using a time-dependent adaptive filter," *IEEE Trans. Commun.*, vol. 43, no. 2/3/4, pp. 187-190, February-March-April 1995.

81. B. D. Woerner, J. H. Reed, and T. S. Rappaport, "Simulation issues for future wireless modems," *IEEE Commun. Mag.*, vol. 32, no. 7, pp. 42-53, July 1994. (invited paper)

82. R. Mendoza, J. H. Reed, T. C. Hsia, and B. G. Agee, "Interference rejection using the generalized constant modulus algorithm and the hybrid CMA/SCD," *IEEE Trans. Signal Processing,* pp. 2108-2111, vol. 39, no. 9, September 1991.

83. J. H. Reed and T. C. Hsia, "The performance of time-dependent adaptive filters For interference rejection," *IEEE Trans. Acoustics, Speech, Signal Processing,* vol. 38, no. 8, pp. 1373-1385, August 1990.

Conference Papers:

Accepted on the basis of peer review

1. R. Mahajan, R. Mueller, J. Reed, C Williams, T Cambell, N. Ramakrishnan, "Cultivating Emerging and Blacks Swan Technologies," Proceedings of the ASME 2012 International Mechanical Engineering Congress and Exposition, November 9-15, Huston, TX, 2012.

2. C. Dietrich and J.H. Reed, "OSSIE SCA-based Open Source SDR," 2011 IEEE MTT Society's International Microwave Symposium, June 5-10, Baltimore, MD

3. C. Dietrich, E. Wolfe, G. Vanhoy, C. Evans, "Cognitive Radio Testing Using Psychometric Approaches," Wireless Innovation Conference and Product Exposition (SDR'11-WinnCom) November 29-December 2, 2011 in Washington, DCC. Dietrich and J.H. Reed, "OSSIE SCA-based Open Source SDR," 2011 IEEE MTT Society's International Microwave Symposium, June 5-10, Baltimore, MD

4. C. Dietrich, E. Wolfe, G. Vanhoy, C. Evans, “Cognitive Radip Testing Using Psychometric Approaches,” Wireless Innovation Conference and Product Exposition (SDR’11-WinnCom) November 29-December 2, 2011 in Washington, DC.

5. Yaeyoung Yang, William A. Davis, Warren L. Stuzman, S.M. Hasan, Randall Nealy, Carl B. Dietrich and Jeffrey H. Reed; “Antenna Design Strategy and Demonstration for Software-Defined Radio”, SDR’10 November 30^{th} – December 3^{rd}, Washington DC

6. D. Datla, S.M. Hasan, T. Bose, J. Reed, “Computational Accuracy of Distributed Signal Processing in Wireless networks,” SDR’10 November 30^{th} – December 3^{rd}, Washington, DC

7. H, Gaeddertm H, Reedm “Resource Managementwith Real-Time Complexity Monitoring in Software-Defined Radios”, SDR’10 November 30^{th} – December 3^{rd}, Washington, DC

8. C. Gonalez, C. Dietrich, F. Kragh, J. Reed, “SDR Design for Retrofit using Coprocessor and Distributed Architectures,” SDR’10 November 30^{th} – December 3^{rd}, Washington, DC

9. A. Amanna, M.Price, K. Thamavichai, T.Bose, J.H.Reed,”Grey Systems Theory Applications to Wirless Communications”, SDR’10 November 30^{th} – December 3^{rd}, Washington, DC

10. S.Moola, S.M.Hasan, C.Dietrich, J.H.Reed, “Rapid Prototyping of a SDR Based Reconfigurabe MIMO-OFDM Testbed,” SDR’10 November 30^{th} – December 3^{rd}, Washington, DC

11. K.Rele, T.R. Newman, J. Reed, “Security Techniques for Attack Resilient Software Defined Radio,” SDR’10 November 30^{th} – December 3^{rd}, Washington DC

12. Dinesh Datla, S.M. Hasan, Tamal Bose, Jeffrey H. Reed; “Fundamental Issues of Wireless Distributed Computing in SDR Networks,” SDR’10 November 30^{th} – December 3^{rd}, Washington DC.

13. C. Nikhil, J. O-Jeong, C. Dietrich, T.R. Newman, J. Reed, "Evaluation Optimization Techniques for Software Defined Radio Cognitive Radio System Performance", SDR'10 Nov. 30 - Dec 3, 2010 Washington, DC

14. Sabares Moola, S.M. Hasan, Carl B. Dietrich, and Jeffrey H. Reed; “Integration of a SDR Based Reconfigurable MIMO-OFDM Testbed into OSSIE, SDR’10 November 30^{th} – December 3^{rd}, Washington DC.

15. Xueato Chen, S.M. Hasan, Tamal Bose, and Jeffrey H. Reed; “Software Defined Radio Based WirelessGrids” SDR’10 November 30^{th} – December 3^{rd}, Washington DC.

16. C. R. Aguayo Gonzalez and J. H. Reed, “Power Fingerprinting in Unauthorized Software Execution Detection for SDR Regulatory Compliance,” Proceedings of the SDR’10,. Washington DC, December, 2010.

17. T.Newman, C.Clancy, M.McHenry, and Jeffrey H. Reed,”Case Studey:Security Analysis of a Dynamic Spectrum Access Radio System,” IEEE Military Communications Conference MILCOM 2010, Oct. 31-Nov4, 2010 San Jose, CA

18. C. R. Aguayo Gonzalez and J. H. Reed, “Detecting Unauthorized Software Execution in SDR using Power Fingerprinting, IEEE MILCOM 2010. November, 2010.

19. Amanna, M. Price, S. Bera, M. Gadhiok, J.H. Reed, "Cognitive Architecture for Railway Communications", Proceedings of the 2010 ASME Rail Transportation Division Fall Technical Conference, Roanoke, VA, October 2010.

20. Dinesh Datla, Xuetao Chen, Timothy Newman, Jeffrey H. Reed, Tamal Bose, “Power Efficiency in Wireless Network Distributed Communications," IEEE Vehicular Technology Conference, Anchorage, Alaska, September 20-23, 2010

21. Dietrich, C., F. Kragh, S.M. Hasan, J.H. Reed, D. Miller, S.H. Edwards, "Enhancements to Software Defined Radio Design Engineering Education," *ASEE SE Section Annual Conference*, April 18-20, 2010

22. Dietrich, C., F. Kragh, S.M. Hasan, C. Aguayo Gonzalez, A. Adenariwo, H.I. Volos, C. Detrich, D. Miller, J. Snyder, S.H. Edwards, J.H. Reed, "Implementation and Evaluation of Laboratory/Tutorial Exercises for Software Defined Radio Education," ASEE SE Section Annual Conference, April 18-20, 2010.

23. Amanna, M. Gadhiok, M. Price, J.H. Reed, W. Siriwongpairat, T. Himsoon, "Rail-CR: Cognitive Radio for Enhanced Railway Communications", Proceedings of Joint ASME (IEEE) Railway Conference, Urbana, IL, April 2010.

24. Amanna and J. H. Reed, “Survey of Cognitive Radio Architectures”, IEEE Southeastcon 2010 – Energizing Our Future, in Charlotte, NC, March 18 – 21 2010

25. X. Chen, T.R. Newman, D. Datla, T. Bose, J.H. Reed, “ The Impact of Channel Variances on the Wireless Distributed Computing Networks”; *Proceedings of the IEEE Global Communications Conference* Honolulu, HI.; November 30 – December 4, 2009.

26. He, S. Srikanteswara, K. Bae, T. R. Newman, J.H. Reed, W. H. Tranter, M. Sajadieh, and M. Verhelst, “System Power Consumption Minimization for Multichannel Communications Using Cognitive Radio, “ in COMCAS 2009, Tel Aviv, Israel Nov. 9 – 11, 2009.

27. Dinesh Datla, Xuetao Chen, Timothy Newman, Jeffrey Reed, and Tamal Bose,“Power Efficiency in Wireless Network Distributed Computing.” Appeared in the Proceedings of the IEEE VTC-Fall 2009 Conference held September 20-23 in Anchorage, Alaska

28. D. Datla, T. Tsou, T. R. Newman, J. H. Reed, and T. Bose, “Waveform level computational energy management in software defined radios.” *SDR Forum*, December 2009. (won best paper award)

29. J. D. Gaeddert and J. H. Reed, “Leveraging software flexibility for managing power consumption in baseband processing,” *SDR Forum*, December 2009.

30. T. Tsou, J. Reed, “ Software Architecture for Cooperative Applications,” SDR Forum Technical Conference, November 1-4, 2009 in Washington DC.

31. M. Carrick, S. Sayed, C. B. Dietrich, and J. H. Reed, “Integration of FPGAs into SDR via memory-mapped I/O,” *SDR Forum*, December 2009.

32. S. Moola, C. Aguayo Gonzalez, C. B. Dietrich, and J. H. Reed, “Distributed wireless computing with multiple domains.” *SDR Forum*, December 2009.

33. Aguayo Gonzalez and J. H. Reed, “Dynamic power consumption monitoring in SDR regulatory compliance,” *SDR Forum*, December 2009.

34. He, T. R. Newman, J. H. Reed, W. H. Tranter, M. Sajadieh, M. Verhelst, S. Srikanteswara, and K. K. Bae, “Power consumption minimization for MIMO systems using cognitive radio,” *SDR Forum*, December 2009.

35. J. D. Gaeddert and J. H. Reed, “Leveraging software flexibility for managing power consumption in baseband processing.” *SDR Forum*, December 2009.

36. X. Chen, T. R. Newman, D. Datla, T. Bose, and J. H. Reed, “The impact of channel variations on wireless distributed computing networks.” IEEE Global Commun. Conf., (GlobeCom), November-December 2009.

37. He, S. Srikanteswara, K. K. Bae, T. R. Newman, J. H. Reed, W. H. Tranter, M. Sajadieh, and M. Verhelst, “System power consumption minimization for multichannel communications using cognitive radio,” *IEEE International Conf. Microwaves, Commun., Antennas Electronic Syst. (COMCAS)*, November 2009.

38. C.A. Gonzalez, J.H. Reed,” Power Fingerprinting in SDR & CR Integrity Assessment, IEEE MILCOM 2009 in Boston, MA, October 18 – 21, 2009.

39. L. Morales, J.E. Suris, J.H. Reed,” A Hybrid Cognitive Engine for Improving Coverage in 3G Wireless Networks”’ *IEEE ICC Joint Workshop on Cognitive Wireless Networks and Systems*, June, 2009.

40. Donglin Hu, Shiwen Mao, and Jeffrey H. Reed, "On video multicast in cognitive radio networks," in *Proc. IEEE INFOCOM 2009*, Rio de Janeiro, Brazil, pp.2222-2230, April 2009.

41. Youping Zhao, Shiwen Mao, Jeffrey H. Reed, and Yingsong Huang, "Experimental study of utility function selection for video over cognitive radio networks," in *Proc. TRIDENTCOM 2009*, Washington D.C., pp.1-10, April 2009.

42. He, S. Srikanteswara, J. H. Reed, X. Chen, W. H. Tranter, K. K. Bae, and M. Sajadieh, “Minimizing energy consumption using cognitive radio,” *IEEE Int. Conf. Performance, Computing Commun., (IPCCC),* December 2008, pp. 372-377.

43. Ramkumar, T. Bose, J. Reed, and M. Radenkovic, “Minimizing energy consumption using cognitive radio: Combined blind equalization and automatic modulation classification for cognitive radios under MIMO environment,” *IEEE DySPAN Symposium*, October 2008.

44. Gonzales, C. Dietrich, and J. H. Reed, “Distributed SDR applications for distance learning,” *IEEE DySPAN Symposium*, October 2008.

45. Dieteich, D. Kumaraswamy, S. Raghunandan, L. Le, and J. H. Reed, “Open space radio: An open source implementation of STRS 1.01,” *IEEE DySPAN Symposium*, October 2008.

46. T. Newman, X. Chen, D. Datla, H. Volos, C. Dietrich, T. Bose, and J. H. Reed, “Cornet” cognitive radio mesh and dynamic spectrum allocation demonstration,” *IEEE DySPAN Symposium*, October 2008.

47. R. Chembil Palat, A. Annamalai, and J. H. Reed, “Log-likelihood-radio based selective decode and forward cooperative communication,” *IEEE Veh. Technol. Conf.*, May 2008 pp. 615-618

48. R. Chembil Palat, A. Annamalai, and J. H. Reed, “Log-likelihood-radio based selective decode and forward cooperative communication,” *IEEE Veh. Technol. Conf.*, May 2008.

49. R. Chembil Palat, A. Annamalai, and J. H. Reed, “Precise error rate analysis of bandlimited BPSK system with timing errors and cochannel interference under generalized fast fading channels,” *IEEE Veh. Technol. Conf.*, May 2008, pp. 1306–1310.

50. M. H. Seung, Mao, K. Nam and J. H. Reed, “On concurrent transmissions in multi-hop wireless networks with shadowing channels,” *IEEE Int. Conf. Commun.*, May 2008, pp. 2662-2666.

51. K. Kim, C. M. Spooner, I. Akbar, and J. H. Reed, “Specific emmitter indentification for cognitive radio with application,” *IEEE Global Commun. Conf.*, Nov.-Dec. 2008, pp. 1–5.

52. S. Mao, J. H. Reed, and Y. Zhao, “Experimental study of utility functions selection for video over IEEE 802.22 wireless regional area networks,” *TRIDENTCOM*, 2009

53. M. Shiwen, J. H. Reed, and H. Donglin, “”On video multicast in cognitive Radio networks, *INFOCOM*, April 2009.

54. R. Chembil Palat, A. Annamalai, and J. H. Reed, “Precise error rate analysis of bandlimited BPSK system with timing synchronization errors and asynchronous cochannel interference under generalized rapid-fading channels,” *IEEE Veh. Technol. Conf. (VTC)*, May 2008.

55. R. Chembil Palat, A. Annanalai, and J. H. Reed, “Efficient computation of information outage probability and ergodic capacity of OSTBC systems,” *IEEE Veh. Technol. Conf. (VTC)*, May 2008, pp. 1428–1432.

56. S. Haykin, J. H. Reed, and D. Thomson, “Spectrum sensing for cognitive radio,” *IEEE Proceedings*, vol. 97, no. 5, pp. 849-877, May 2009.

57. X. Chen, T. Bose, A. He, and J. H. Reed, "A high efficiency outphasing transmitter structure for wireless communications," *IEEE DSP Workshop*, January 2009.

58. S. M. Hur, S. Mao. K. Nam, and J. H. Reed, “On concurrent transmissions in multi-hop wireless networks with shadowing channels,” *IEEE ICC*, May 2008.

59. J. H. Reed, C. Dietrich, D. Miller, and F. Kragh, "Education in software defined radio design engineering", *Proceedings CD*, ASEE, ECD Division Program, February 2008.

60. S. H. Won, H. J. Park, J. O. Neel, and J. H. Reed, "Inter-cell interference coordination/avoidance for frequency reuse by resource scheduling in and OFDM-based cellular system," *66th IEEE Veh. Technol. Conf. (VTC)*, September–October 2007, pp. 1722–1725.

61. Y. Zhao, J. Gaeddert, L. Morales, K. K. Bae, and J. H. Reed, "Development of radio environment map enabled case-and knowledge-base learning algorithms for IEEE 802.22 WRAN cognitive engines," *2nd International Conf. Cognitive Radio Oriented Wireless Networks Commun. (CROWNCOM),* August 2007.

62. J.-H. Kim; K. K. Bae, J. H. Reed, and A. Annamalai, "Capacity and coverage of reverse link DS/CDMA cellular systems with MIMO implementations," *IEEE International Conference Commun. (ICC)*, June 2007, pp. 5897-5902.

63. R. Menon, A. B. Mac Kenzie, R. M. Buehrer, and J. H. Reed, "Joint power control and waveform adaptation for distributed networks," *IEEE Global Commun. Conf. (GlobeCom)*, November 2007, pp. 694-699.

64. R. Aguayo Gonzalez and J. H. Reed, "Validation and verification of modular software for software-defined radios," *Software Defined Radio Conference (SDR Forum)*, November 2007.

65. R. Aguayo Gonzalez and J. H. Reed, "Dynamic spectrum access assessment in cognitive radios," *Software Defined Radio Conference (SDR Forum)*, November 2007.

66. J. Gaeddert, H. I. Volos, D. Cormier, and J. H. Reed, "Multi-rate synchronization of digital receivers in software-defined radios," *Software Defined Radio Conference (SDR Forum)*, November 2007.

67. Y. Zhao, D. Raymond, C. daSilva, J. H. Reed, and S. F. Midkiff, "Performance evaluation of radio environment map-enabled cognitive sharing networks," *IEEE Military Commun. Conf. (MILCOM)*, October 2007, pp. 1-7.

68. J. H. Kim, K. K. Bae, and J. H. Reed, "Capacity and coverage of reverse link DS/CDMA cellular systems with MIMO implementations." *IEEE International Conf. Commun. (ICC)*, June 2007, pp. 5897-5902.

69. J. O. Neel, R. Menon, A. B. MacKenzie, and J. H. Reed, "Interference reducing networks," *CrownCom*, August 2007, pp. 96-104.

70. Y. Zhao, L. Morales, J. Gaeddert, K. K. Bae, J.-S. Um, and J. H. Reed, "Applying radio environment maps to cognitive wireless regional area networks," *DYSPAN Conf.*, April 2007.

71. K. Kim, I. A. Akbar, K. K. Bae, J.-S. Um, and J. H. Reed, "Cyclostationary approaches to signal detection and classification in cognitive radio," *DYSPAN Conf.*, April 2007.

72. R. Menon, A. B. MacKenzie, R. M. Buehrer, and J. H. Reed, "A game-theoretic framework for interference avoidance in ad hoc networks," *IEEE GlobeCom*, November-December 2006.

73. J. O. Neel and J. H. Reed, "Performance of distributed dynamic frequency selection schemes for interference reducing networks," *IEEE MILCOM*, October 2006.

74. Y. Zhao, J. H. Reed, S. Mao, K. K. Bae, "Overhead analysis for radio environment map (REM)-enabled cognitive radio networks," *IEEE Conf. Sensor, Mesh, Ad Hoc Commun. Networks (SECON)*, September 2006.

75. S. Venkatesh, C. R. Anderson, R. M. Buehrer, and J.H. Reed, "On the use of pilot-assisted matched filtering in UWB time-interleaved sampling," *International Conf. Ultra-Wideband (ICUWB)*, September 2006, pp. 119-124.

76. J. O. Neel, M. Robert, and J. H. Reed, "A formal methodology for estimating the feasible processor solution space for a software radio," *Software Defined Radio Forum (SDR Forum)*, November 2005, pp. A117-A122.

77. C. Anderson and J. H. Reed, "Performance analysis of a time-interleaved sampling for a software defined ultra wideband receiver," *Software Defined Radio Forum (SDR Forum)*, November 2005, pp. A75-A80.

78. R. Chembil Palat, A. Annamalai, and J. H. Reed, "Cooperative relaying for ad-hoc ground networks using Swarm UAVS," *IEEE Military Commun. Conf. (MILCOM),* October 2005, pp. 3314-3320.

79. N. Ryu, Y. Yun, S. Choi, and J. H. Reed, "Smart antenna implemented with reconfigurable devices for ADR network," *IEICE Technical Committee Software Radio,* July 2005, pp. 15-22.

80. J.-H. Kim, K. K. Bae, A. Annamalai, and J. H. Reed, "The impact of transmit diversity on the Erlang capacity of reverse link DS/CDMA," *International Symposium Personal Indoor Mobile Radio Commun. (IPMRC)*, September 2005.

81. S. Mao, X. Cheng, Y. T. Hou, H. Sherali, and J. Reed, "Joint routing and server selection for multiple description video streaming in ad hoc networks," *IEEE International Conf. Commun. (ICC)*, May 2005, pp. 2993-2999.

82. Y. T. Hou, Y. Shi, J. H. Reed, and K. Sohraby, "Flow routing for variable bit rate source nodes in energy-constrained wireless sensor networks" *IEEE International Conf. Commun. (ICC)*, May 2005, pp. 3057-3062.

83. K. K. Bae, J.-H. Kim, A. Annamalai, W. H. Tranter, and J. H. Reed, "Impact of transmit diversity at handsets on the reverse link DS/CDMA system capacity," *IEEE Global Commun. Conf. (GLOBECOM)*, November-December 2004, vol. 6, pp. 3700-3704.

84. J. A. Neel, J. H. Reed, and R. P. Gilles, "Game models for cognitive radio algorithm analysis," *Software Defined Radio Forum (SDR Forum)*, November 2004. (Best Paper Award)

85. R. Menon, R. M. Buehrer, J. H. Reed, and A. MacKenzie, "Game theory and interference avoidance in decentralized networks," *Software Defined Radio Forum (SDR Forum)*, November 2004.

86. J. O. Neel, S. Srikanteswara, J. H. Reed, and P. M. Athanas, "A comparative study of the suitability of a custom computing machine and a VLIW DSP for use in 3G applications," *IEEE Workshop Signal Processing Systems (SiPS),* October 2004, pp. 188-193. Alam, B. L. P. Cheung, R. Mostafa, W. G. Newhall, B. D. Woerner, and J. H. Reed, "Sub-band beamforming for OFDM systems in practical channel condition," *IEEE Veh. Technol. Conf. (VTC Fall),* September 2004, vol. 1, pp. 235-239.

87. J.-H. Kim, K. K. Bae, A. Annamalai, W. H. Tranter, and J. H. Reed, "Reverse link Capacity and interference statistics of DS/CDMA with transmit diversity," *IEEE Veh. Technol. Conf. (VTC Fall),* September 2004, vol. 6, pp. 4320-4324.

88. J. A. Neel, J. H. Reed, and R. P. Gilles, "Convergence on cognitive radio networks," *IEEE Wireless Commun. Networking Conf. (WCNC)*, March 2004.

89. D. Murotake, A. Fuchs, A. Martin, B. Fette, J. H. Reed, and P. M. Robert, "A lightweight software communications architecture (SCA) launcher implementation for embedded radios," *Software Defined Radio Technical Conf. Product Exposition (SDR Forum),* November 2003, paper SW3-001.

90. W. G. Newhall, R. Mostafa, C. Dietrich, C. Anderson, K. Dietze, G. Joshi, and J. H. Reed, "Wideband air-to-ground radio channel measurements using an antenna array at 2 GHz for low-altitude operations," *IEEE Military Commun. Conf. (MILCOM),* October 2003, vol. 2, pp. 1422-1427.

91. S. W. Kim, D. S. Ha, and J. H. Reed, "Minimum selection GSC and adaptive low-power rake combining scheme," *IEEE International Symposium Circuits Systems (ISCAS)*, May 2003.

92. M. A. Nizamuddin, P. H. Balister, W. H. Tranter, and J. H. Reed, "Nonlinear tapped delay line digital predistorter for power amplifiers with memory," *IEEE Wireless Commun. Networking Conf.*, March 2003.

93. W. Newhall and J. H. Reed, "A geometric air-to-ground radio channel model," *IEEE Military Commun. Conf. (MILCOM),* October 2002, pp. 632-636.

94. B. Cheung, F. Alam, J. H. Reed, and B. D. Woerner, "New adaptive beamforming algorithm for OFDM systems," *14th International Conf. Wireless Commun. (Wireless)*, July 2002, pp. 71-75. (URSI Best Student Paper Award)

95. J. Hicks, J. Tsai, J. H. Reed, and W. H. Tranter, "Overloaded array processing with MMSE-SIC," *IEEE Veh. Technol. Conf. (VTC – Spring)*, May 2002, pp. 542-546.

96. S. Krishnamoorthy, C. R. Anderson, S. Srikanteswara, P. M. Robert, and J. H. Reed, "Background interference measurements at 2.45GHz in a hospital," *1st Student Research Symposium Virginia Tech Center Biomedical Engineering, Wake Forest University School Medicine*," May 2002.

97. M. C. Valenti, M. Robert, and J. H. Reed, "On the throughput of Bluetooth data transmissions," *IEEE Wireless Commun. Networking Conf. (WCN)*, March 2002, vol. 1, pp. 119-123.

98. W. Newhall and J. H. Reed, "A geometrically based radio channel model for air-to-ground communications," *Virginia Space Grant Consortium*, March 2002.

99. S. Srikanteswara, J. Neel, J. H. Reed, and P. Athanas, "Soft radio implementations 3G future high data rate systems," *IEEE Global Commun. Conf. (GLOBECOM)*, November 2001, vol. 6, pp. 3370-3374.

100. R. Mostafa, A. Hannan, J. H. Reed, and W. H. Tranter, "Narrowband transmit diversity measurements at the handset for an indoor environment," *ICICS*, accepted, not presented, October 2001.

101. J. Kim, Y. M Vasavada, and J. H. Reed, "Spatio-temporial searcher structure for 3G W-CDMA smart antenna systems," *IEEE Veh. Technol. Conf. (VTC – Fall)*, October 2001, vol. 3, pp. 1635-1639.

102. J. Kim, K. Zahid, and J. H. Reed, "Performance evaluation of 3G W-CDMA smart antenna systems for rural area multi-path fading environments," *WPMC,* accepted, not presented, September 2001.

103. R. Gozali, R. Mostafa, R. Chembil Palat, S. Marikar, P. M. Robert, W. G. Newhall, C. Beaudette, S. A. Tsaikkou, B. D. Woerner, and J. H. Reed, "Virginia tech space-time advanced radio," *IEEE Radio Wireless Symp. (RAWCON)*, August 2001, pp. 227-231.

104. P. Balister, M. Nizamuddin, M. Robert, W. H. Tranter, and J. H. Reed, "Role of signal envelope distribution in predicting the performance of a multicarrier communication system," *IEEE Radio Wireless Symp. (RAWCON)*, August 2001, pp. 245-248.

105. R. Gozali, S. Bayram, J. Tsai, B. D. Woerner, and J. H. Reed, "Interpolation based data-aided timing recovery scheme for multi-user CDMA receivers," *Wireless Conf.*, July 2001, pp. 544-548.

106. M. Robert and J. H. Reed, "Software design issues in networks with software-defined-radio nodes," *WETICE Conf.*, June 2001, pp. 55-59.

107. T. E. Biedka, J. H. Reed, and W. H. Tranter, "Mean convergence rate of a decision directed adaptive beamformer with Gaussian interference," *IEEE Sensor Array Multichannel Signal Processing Workshop (SAM),* March 2000.

108. N. D. Tripathi, J. H. Reed, and H. F. VanLandingham, "Pattern classification based handoff using fuzzy logic and neural nets," *IEEE International Conf. Commun. (ICC)*, June 1998, section 48, paper 2.

109. S. K. Yao and J. H. Reed, "GMSK differential detectors with decision feedback in multipath and CCI channels," *IEEE Global Commun. Conf. (GLOBECOM)*, November 1996, pp. 1830-1834.

110. P. Petrus, T. S. Rappaport, and J. H. Reed, "Geometrically based statistical macrocell channel model for mobile environments," *IEEE Global Commun. Conf. (GLOBECOM)*, November 1996, pp. 1197-1201.

111. N. Mangalvedhe and J. H. Reed, "An Eigenstructure technique for soft synchronization of spread spectrum," *IEEE Conf. Acoustics, Speech Signal Processing*, May 1996, pp. 1751-1754.

112. P. Petrus, I. Howitt, and J. H. Reed, "Evaluation of outage probability due to co-channel interference in fading for an AMPS system with an ideal beamformer," *Wireless Conf.*, July 1996, pp. 29-40.

113. R. He and J. H. Reed, "AMPS interference rejection by exploiting the SAT information," *IEEE Personal, Indoor, Mobile Radio Commun. (PIMRC)*, September 1995, pp. 597-602.

114. P. Petrus and J. H. Reed, "Co-channel interference rejection for AMPS signals using spectral correlation properties and an adaptive array," *IEEE Veh. Technl. Conf. (VTC)*, July 1995, pp. 30-34.

115. P. Petrus and J. H. Reed, "Least squares CM adaptive array for co-channel interference rejection for AMPS and IS-54," *Wireless Conf.*, July 1995, pp. 7.41-7.47.

116. J. Cheng, P. Lemson, J. H. Reed, and I. Jacobs, "A dynamic range enhancement technique for fiber optic microcell radio systems," *IEEE Veh. Technl. Conf. (VTC)*, July 1995, pp. 774-778.

117. S. P. Neugebauer and J. H. Reed, "Prediction of maximal length pseudorandom sequences using neural networks" *Artificial Neural Networks Engineering (ANNIE)*, November 1994, pp. 675-680.

118. R. J. Holley and J. H. Reed, "Time dependent adaptive filters for interference cancellation in CDMA systems," *Workshop Cyclostationary Signal Processing*, August 1994.

119. Howitt, R. Vemuri, J. H. Reed, and T. C. Hsia, "Comparison of center estimation methods for RBF networks," *IMAC Conf.*, July 1994, pp. 1304-1306.

120. Howitt, R. Vemuri, J. H. Reed, and T. C. Hsia, "RBF growing algorithm applied to equalization and co-channel interference rejection problem," *IEEE World Congress Computational Intelligence/International Conf. Neural Networks*, June-July 1994, pp. 3571-3576.

121. T. Yang, J. H. Reed, and T. C. Hsia, "Spectral correlation Of BPSK and QPSK signals in a nonlinear channel With AM/AM and AM/PM conversions," *IEEE International Conf. Commun.*, pp. 627-632.

122. J. H. Reed, A. A. Quilici, and T. C. Hsia, "A frequency domain time-dependent adaptive filter for interference rejection," *IEEE Military Commun. Conf. (MILCOM)*, October 1988, pp. 391-397.

123. J. H. Reed and T. C. Hsia, "A technique for sorting and detecting signals in interference," *IEEE Military Commun. Conf. (MILCOM)*, October 1988, pp. 425-430.

Accepted on the basis of abstract

1. C. Dietrich and J.H. Reed, “OSSIE SCA-based Open Source SDR,” 2011 IEEE MTT Society’s International Microwave Symposium, June 5-10, Baltimore, MD

2. C. Dietrich, E. Wolfe, G. Vanhoy, C. Evans, “Cognitive Radio Testing Using Psychometric Approaches,” Wireless Innovation Conference and Product Exposition (SDR’11-WinnCom) November 29-December 2, 2011 in Washington, DC

3. M.Gadhiok, A.Amanna, M. Price, J.H. Reed, “Metacognition: Enhancing The Performance of a Cognitive radio,” IEE CogSIMA Conference, Feb 22-24, 2011 Miami Beach, Florida

4. M Khedr, H. Shatila, J. Reed, “Adaptive Reseource Management for Vague Environment Using Cognitive Radio”, ICCST Conference, July 9-11, 2010 Changdu, China

5. H.Shatila, M. Khedr and J. Reed, “Adaptive Modulation and Coding for WiMAX Systmes with Vague Channel State Information using Cognitive Radio”, SOECT 2010, Ottawa, Canada, July 2010

6. Amanna, J. H. Reed, “Survey of Cognitive Radio Architectures”, IEEE Southeast Conference 2010, in Charlotte, NC, March 18-21, 2010.

7. F. Kragh, C. Dietrich, S.M. Hasan, J.H. Reed, D. L. Miller, S. H. Edwards, “ Enhancements to Software Defined Radio Design Engineering Education”, 2010 ASEE Southeast Section Conference, April 18-20, 2010 in Blacksburg, VA.

8. S.M. Hasan, R. Nealy, T. Briseboie, T.R. Newman, T. Bose, J.H. Reed, “Wideband RF Front End Design Considerations for Flexiable White Space Software Defined Radio” [Invited Paper] 2010 Radio and Wireless Symposium (RWS), New Orleans, LA, January 10 – 14, 2010.

9. X. Chen, S.M. Hasan, T. Bose, J.H.Reed, “Cross-Layer Reseource Allocation for Wireless Computing Networks”, 2010 Radio and Wireless Symposium (RWS), New Orleans, LA, January 10 – 14, 2010.

10. S.M. Hasan, R. Nealy, T Brisebois, T.R. Newman, T. Bose, and J.H. Reed, “Wideband RF Front End Design Considerations for a Flexible White Space Software Defined Radio” [invited paper] 2010 Radio and Wireless Symposium (RWS)” in New Orleans, LA, January 10-14, 2010

11. X.Chen, S.M. Hasan, T. Bose, and J.H. Reed, “Cross-Layer Resources Allocation for Wireless Distributed Computing Networks” 2010 Radio and Wireless Symposium (RWS)” in New Orleans, LA, January 10-14, 2010

12. M.Khedr, H. Shatila, J. Reed "Adaptive resource Management for Vague Environment Using Cognitive Radio", ICCSIT conference, July 9-11 in Chengdu, China

13. S. Hazem, K. Mohamed, and J. H. Reed, “Channel estimation for WiMAX systems using fuzzy logic cognitive radio” *WOCN Conf.*, April 2009.

14. C. Gonzales, C. Dietrich, and J. H. Reed, “Distributed SDR applications for distance learning,” *SDR Forum*, October 2008.

15. J. Neel, S. Sayed, M. Carrick, C. Dietrich, and J. H. Reed, "PCET" a tool for rapidly estimating statistics of waveform components implemented on digital signal processors," *SDR Forum*, October 2008.

16. C.Dietrich, D. Kumaraswamy, S. B. Raghundndan, L. Lee, and J. H. Reed, "Open space radio: An open source implementation of STRS 1.01," *SDR Forum*, October 2008.

17. R. Farrell, A. Wyglinski, C. R. Anderson, J. H. Reed, P. Balister, C. Phelps, T. Tous, J. Gaeddert, C. Aguayo, S. Bilen, G. Nychis, J. Chapin, B. Farhang-Boroujeny, N. Pawari, and J. Schiel, "Rationale for clean slate radio architecture," submitted *SDR Forum*, October 2008.

18. J.-H. Kim, K. K. Bae, and J. H. Reed, "Transmit and receiver diversity in the uplink of DS/CDMA cellular systems," *IEEE Veh. Technol. Conf. (VTC Spring 2007)*, April 2007.

19. C. A. Gonzalez, F. Portelinha, and J. H. Reed, "Design and implementation of an SCA core framework for a DSP platform," *SDR Forum*, November 2006.

20. C. R. Anderson and J. H. Reed, "Development of and initial performance results for a software defined ultra wideband receiver," *SDR Forum 2006*, November 2006.

21. J. Neel, J. H. Reed, and C. A. Gonzalez, "Automated waveform partitioning and optimization for SCA waveforms," *SDR Forum,* November 2006.

22. S. M. Hasan, P. Balister, K. Lee, J. H. Reed, and S. Ellingson, "A LOW cost MULTI-band/MULTI-mode radio for public safety," *SDR* Forum, November 2006.

23. Y. Zhao, J. Gaeddert, K. K. Bae, and J. H. Reed, "Radio environment map-enabled situation-aware cognitive radio learning algorithms," *SDR* Forum, November 2006.

24. P. Balister, M. Robert, and J. H. Reed, "Impact of the use of COBRA for inter-component communication in SCA based radio," *SDR* Forum, November 2006.

25. R, Menon, R. M. Buehrer, and J. H. Reed, "Impact of exclusion region and spreading spectrum-sharing ad hoc networks," *Workshop Technol. Policy Accessing Spectrum (TAPAS)*, August 2006.

26. R. Chembil Palat, A. Annamalai, and J. H. Reed, "Node density and range improvement in cooperative networks using randomized space-time block coding with time synchronization errors," *4th IEEE Workshop Sensor Array Multichannel Processing (SAM)*, July 2006, pp. 466-470.

27. R. Chembil Palat, A. Annamalai, and J. H. Reed, "Probability of error analysis under arbitrary fading and power allocation for decode and forward cooperative communication," *IEEE Communication Theory Workshop (CTW)*, May 2006. (No printed proceedings available.)

28. R. Chembil Palat, J. Kim, J. S. Lee, D. S. Ha, C. Patterson, and J. H. Reed, "Reconfigurable modem architecture for CDMA based 3G handsets," *SDR Forum*, November 2005, pp. B119-B125.

29. R. Menon, R. M. Buehrer, and J. H. Reed, "Outage probability based comparison of underlay and overlay spectrum sharing techniques," *Dynamic Spectrum Access Networks, (DySPAN)*, November 2005, pp. 101-109.

30. Fehske, J. Gaeddert, and J. H. Reed, "A new approach to signal classification using spectrum correlation and neural networks," *Dynamic Spectrum Access Networks, (DySPAN)*, November 2005, pp. 144-150.

31. R. Chembil Palat, A. Annamalai, and J. H. Reed, "Cooperative relaying of ad-hoc ground networks using SWARM UAVS," *IEEE Military Commun. Conf. (MILCOM)*, October 2005. (Page numbers not available.)

32. J. Kim, K. K. Bae, A. Annamalai, and J. H. Reed, "The impact of transmit diversity on the Erlang capacity of reverence link DS/CDMA system," *IEEE International Symposium Personal Indoor Mobile Radio Commun.(PIMRC)*, September 2005. (Proceedings on CD ROM only, no page numbers available.)

33. Y. Zhao, B. G. Agee, and J. H. Reed, "Simulation and measurements of microwave oven leakage for 802.11 WLAN interference managements," *IEEE International Symposium Microwave, Antenna, Propagation, EMC Technologies Wireless Commun. (MAPE),* August 2005, pp. 1580-1583.

34. J. Neel, R. Menon, J. H. Reed, and A. B. MacKenzie, "Using game theory to analyze physical layer cognitive radio algorithms," *Conf. Economics, Technol., Policy Unlicensed Spectrum,* May 2005. (No proceedings available.)

35. R. Mostafa, P. Khanna, W. C. Chung, J. W. Heo, J. H. Reed, and D. S. Ha, "Performance evaluation of 2D rake algorithms for WCDMA-DL applications at the handset," *IEEE Radio Wireless Conf. (RAWCON*), September 2004.

36. C. R. Anderson, S. Krishnamoorthy, C. G. Ranson, T. J. Lemon, W. G. Newhall, T. Kummetz, and J. H. Reed, "Antenna isolation, wideband multipath propagation measurements and interference mitigation for on-frequency repeaters," *IEEE SouthEastCon*, March 2004, pp. 110-114.

37. Y. Ahmed, J. H. Reed, W. H. Tranter, and R. M. Buehrer, "A model-based approach to demodulation of co-channel MSK signals," *IEEE Global Commun. Conf. (GLOBECOM*), December 2003, pp. 2442-2446.

38. J. A. Neel, M. Robert, A. Hebbar, R. Chembil Palat, J. H. Reed, S. Srikanteswara, R. Menon, and R. Kumar, "Critical technology challenges to the commercialization of software radio," *World Wireless Research Forum*, October 2003.

39. S. Krishnamoorthy, J. H. Reed, C. R. Anderson, P. M. Robert, and S. Srikanteswara, "Characterization of the 2.4 GHz ISM band electromagnetic interference in a hospital environment," *25th Annual IEEE Conf. IEEE Engineering Medicine Biology Society*, September 2003.

40. R. Mostafa, K. Dietze, R. B. Ertel, C. Dietrich, J. H. Reed, and W. L. Stutzman, "Wideband characterization of wireless channels for smart antenna Applications," *IEEE Radio Wireless Conf. (RAWCON),* August 2003, pp. 103-106.

41. R. Mostafa, M. Robert, and J. H. Reed, "Reduced complexity MIMO processing for WLAN (IEEE 802.11b) applications," *IEEE Radio Wireless Conf. (RAWCON),* August 2003, pp. 171-174.

42. S. W. Kim, D. S. Ha, and J. H. Reed, "Minimum selection GSC and adaptive low-power rake combining scheme," *International Symposium Circuits Systems (ISCAS)*, May 2003, pp. IV-357—IV-360.

43. F. Alam, R. Mostafa, B. Cheung, B. D. Woerner, and J. H. Reed, "Frequency domain beamforming for OFDM system in practical multipath channel," *ICECE Conf.*, December 2002.

44. S. Srikanteswara, J. Neel, J. H. Reed, and S. Sayed, "Resource allocation in software radios using CCMs based on the SCA," *SDR Forum*, Nov. 2002.

45. J. Neel, J. H. Reed, and R. P. Gilles, "The role of game theory in the analysis of software radio networks," *SDR Forum*, November 2002.

46. R. Gozali, R. Mostafa, R. Chembil Palat, P. M. Robert, W. G. Newhall, B. D. Woerner, and J. H. Reed, "MIMO channel capacity measurements using the Virginia Tech space-time advanced radio (VT-STAR)," *IEEE Veh. Technol. Conf. (VTC Fall)*, September 2002, pp. 884-888.

47. J. E. Hicks, J. Tsai, J. H. Reed, W. H. Tranter, and B. D. Woerner, "The performance of linear space-time processing in overloaded environments," *14th International Conf. Wireless Commun. (Wireless)*, July 2002, pp. 83-89.

48. J. Neel, M. Buehrer, J. H. Reed, and R. P. Gilles, "Game theoretic analysis of a network of cognitive radios," *IEEE Midwest Symposium Circuits Systems*, August 2002, pp. 409-412.

49. M. Robert, L. A. DaSilva, and J. H. Reed, "Statistical back-off method for minimizing interference among distinct net technologies," *IEEE Veh. Technol. Conf. (VTC Fall),* September 2002, pp. 1725-1729.

50. S. Krishnamoorthy, M. Robert, S. Srikanteswara, M. C. Valenti, C. R. Anderson, and J. H. Reed, "Channel frame error rate for Bluetooth in the presence of microwave oven," *IEEE Veh. Technol. Conf. (VTC Fall),* September 2002, pp. 927-931.

51. W.G. Newhall, R. Mostafa, K. Dietze, J. H. Reed, and W. L. Stutzman, "Measurement of multipath signal component amplitude correlation coefficients versus propagation delay," *IEEE Radio Wireless Conf. (RAWCON)*, August 2002, pp. 133-136.

52. S. Srikanteswara, J. Neel, J. H. Reed, and P. Athanas, "Designing soft radios for high-data rate Systems and integrated global services," *35th Asilomar Conf.*, November 2001, vol. 1, pp. 51-55.

53. F. Alam, K. Zahid, B. D. Woerner, and J. H. Reed, "Performance comparison between pilot symbol assisted and blind beamformer-rake receivers at the reverse link of third generation CDMA system," *IEEE Veh. Technol. Conf. (VTC Fall)*, October 2001, vol. 1, pp. 353-357.

54. Y. M Vasavada, J. Kim, and J. H. Reed, "Receiver structure for W-CDMA space-time processing," *IEEE Veh. Technol. Conf. (VTC Fall)*, October 2001, vol. 4, pp. 1965-1969.

55. R. Mostafa, K. Dietze, R. Chembil Palat, W. L. Stutzman, and J. H. Reed, "Demonstration of real-time wideband transmit diversity at the handset in the indoor wireless channel," *IEEE Veh. Technol. Conf. (VTC Fall)*, October 2001, vol. 4, pp. 2072-2076.

56. T. Beidka, J. H. Reed, and W. H. Tranter, "Mean convergence rate of a decision directed adaptive beamformer with Gaussian interference," *Sensor Array Multichannel Signal Processing Workshop, 2002*, pp. 68-72.

57. S. Srikanteswara, J. H. Reed, and P. M. Athanas, "Implementation of a reconfigurable soft radio using the layered radio architecture," *34th Asilomar Conf. Signals, Systems, Computers*, 2000, pp. 360-364.

58. Y. M. Vasavada, T. E. Biedka, and J. H. Reed, "Code gated algorithm: A blind adaptive antenna array beamforming scheme for the wideband CDMA system," *34th Asilomar Conf. Signals, Systems, Computers*, 2000, pp. 1397-1402.

59. T. E. Biedka, J. H. Reed, and W. H. Tranter, "Statistics of blind signature estimators," *34th Asilomar Conf. Signals, Systems, Computers*, 2000, pp. 847-850.

60. S. Bayram, J. Hicks, R. J. Boyle, and J. H. Reed, "Overloaded array processing in wireless airborne communication systems," *IEEE Military Commun. Conf. (MILCOM)*, October 2000. (Proceedings on CD ROM.)

61. S. Bayram, J. Hicks, R. J. Boyle, and J. H. Reed, "Joint maximum likelihood approach in overloaded array processing," *IEEE Veh. Technol. Conf. (VTC Fall),* September 2000, pp. 394-400.

62. S. Srikanteswara, M. Hosemann, J. H. Reed, and P. M. Athanas, "Design and implementation of a completely reconfigurable soft radio," *IEEE Radio Wireless Conf. (RAWCON),* September 2000, pp. 7-11.

63. M. Hosemann, S. Srikanteswara, and J. H. Reed, "A code tracking technique for direct sequence spread spectrum using adaptive filtering," *IEEE Radio Wireless Conf. (RAWCON)*, September 2000, pp. 25-28.

64. W. L. Stutzman, J. H. Reed, C. B. Dietrich, B. Kim, and D. G. Sweeney, "Recent results from smart antenna experiments: Base station and handheld terminals," *IEEE Radio Wireless Conf. (RAWCON)*, September 2000.

65. T. Biedka, C. Dietrich, K. Dietze, R. Ertel, B. Kim, R. Mostafa, W. Newhall, U. Ringel, J. H. Reed, D. Sweeney, W. L. Stutzman, R. J. Boyle, and A. Tikku, "Smart antenna for handsets," *DSPS Fest*, August 2000. (Proceedings not yet published.)

66. R. Mostafa, N. D. Tripathi and J. H. Reed, "DSP Implementation of Communication Systems," *DSPS Fest 2000,* August 2000. (Proceedings not yet published.)

67. S. Bayram, J. Hicks, R. J. Boyle, and J. H. Reed, "Overloaded array processing: Non-linear vs. linear aignal extraction techniques," *12th Annual International Conf. Wireless Commun. (Wireless),* July 2000, vol. 2, pp. 492-498.

68. K. A. Phillips, J. H. Reed, and W. H. Tranter, “Minimum BER adaptive filtering,” *IEEE International Conf. Commun. (ICC),* June 2000, pp. 310-321.

69. B. Kim, W. L. Stutzman, D. G. Sweeney, and J. H. Reed, “Space, polarization, and angle diversity for cellular base stations operating in urban environments,” *IEEE Antennas Propagation International Symposium,* Salt Lake City, UT, July 16-21, 2000, pp. 940-943.

70. B. Kim, W. L. Stutzman, D. G. Sweeney, and J. H. Reed, “Initial results from an experimental cellular base station with space, polarization, and angle diversity operating in urban environments,” *10th Virginia Tech/MPRG Symposium Wireless Pers. Commun.,* Blacksburg, VA, June 14-16, 2000.

71. P. M. Robert, A. Darwish, and J. H. Reed, “Fast bit error generation for the simulation of MPEG-2 transmissions in wireless systems,” *IEEE Wireless Commun. Networking Conf. (WCNC)*, September 1999.

72. P. M. Robert, A. Darwish, and J. H. Reed, "MPEG video quality prediction in a wireless system," *IEEE Veh. Technol. Conf. (VTC)*, May 1999, vol. 2, pp. 1490-1495.

73. N. D. Tripathi, J. H. Reed, and H. F. VanLandingham, "Fuzzy logic based adaptive handoff algorithms for microcellular systems," *IEEE Veh. Technol. Conf. (VTC),* May 1999, pp. 1419-1424.

74. N. D. Tripathi, J. H. Reed, and H. F. VanLandingham, "Adaptive handoff algorithms for cellular overlay systems using fuzzy logic," *IEEE Veh. Technol. Conf. (VTC),* May 1999, vol. 2, pp. 1413-1418.

75. R. B. Ertel, Z. Hu, and J. H. Reed, "Antenna array hardware amplitude and phase compensation using baseband antenna array outputs," *IEEE Veh. Technol. Conf. (VTC),* May 1999, pp. 1759-1763.

76. P. M. Robert, A. Darwish, and J. H. Reed, "Effect of error distribution in channel coding failure on MPEG wireless transmission," *Electronic Imaging Conf. (SPIE),* January 1999.

77. S. Srikanteswara, P. Athanas, J. H. Reed, and W. H. Tranter, "Configurable computing for communication systems," *International Microelectronics Packaging Society (IMAPS)*, November 1998.

78. N. D. Tripathi, J. H. Reed, and H. F. VanLandingham, "Pattern classification based handoff using fuzzy logic and neural nets," *IEEE International Conf. Commun. (ICC)*, June 1998, section 48, paper 2.

79. R. B. Ertel and J. H. Reed, “Impact of path loss on the Doppler spectrum for the geometrically based single bounce vector channel models,” *IEEE Veh. Technol. Conf. (VTC),* May 1998, vol. 1, pp. 586-590.

80. N. D. Tripathi, J. H. Reed, and H. F. VanLandingham, “An adaptive direction biased fuzzy handoff algorithm with unified handoff selection criterion,” *IEEE Veh. Technol. Conf. (VTC),* May 1998, vol. 1, pp. 127-131.

81. N. D. Tripathi, J. H. Reed, and H. VanLandingham, "An adaptive handoff algorithm using neural encoded fuzzy logic system," *Annie Conf.*, November 1997.

82. J. H. Reed, R. Ertel, P. Cardieri, and T. S. Rappaport, "Vector channel models," *Stanford Workshop Smart Antennas*, July 1997. (Invited presentation.)

83. Z. Rong, T. S. Rappaport, P. Petrus, and J. H. Reed, "Simulation of multi-target adaptive array algorithms for CDMA system," *IEEE Veh. Technol. Conf. (VTC)*, May 1997. (Also *IEEE Smart Antennas: Adaptive Arrays, Algorithms, Wireless Position Location*, 1998, pp. 321-325).

84. N. Zecevic and J. H. Reed, "Blind adaptation algorithms for direct-sequence spread-spectrum CDMA single-user detection," *IEEE Veh. Technol. Conf. (VTC)*, May 1997.

85. N. Mangalvedhe and J. H. Reed, "Blind CDMA interference rejection in multipath channels," *IEEE Veh. Technol. Conf. (VTC)*, May 1997.

86. W. C. Ting and J. H. Reed, "Interference rejection for AMPS using time dependent adaptive filter and model-based demodulation," *IEEE Veh. Technol. Conf. (VTC)*, May 1997.

87. J. H. Reed, "Cell average carrier to interference coverage improvement by using DSP interference rejection techniques," *IEEE Veh. Technol. Conf. (VTC)*, May 1997.

88. D. G. Sweeney and J. H. Reed, "License free wireless operation," *SoutheastCon*, April 1997.

89. T. E. Biedka, B. D. Woerner, and J. H. Reed, "Direction finding methods for CDMA systems," *Asilomar Conf.*, November 1996, pp. 637-641.

90. T. E. Biedka, W. H. Tranter, and J. H. Reed, "Convergence analysis of the least squares constant modulus algorithm," *Asilomar Conf.*, November 1996, pp. 541-545.

91. N. R. Mangalvedhe and J. H. Reed, "Analysis of an eigenstructure technique for DSSS Synchronization," *Virginia Tech's 6th Annual Symposium Wireless Pers. Commun.*, June 1996. (Also *Wireless Personal Communications: The Evolution of PCS*, Kluwer Press, 1996.)

92. B. Tranter, T. S. Rappaport, B. D. Woerner, J. H. Reed, and D. Krizman, "The role of simulation in teaching of communications," *Frontiers Education Conf.*, November 1996, paper 7a1.1.

93. T. S. Rappaport, W. H. Tranter, J. H. Reed, B. D. Woerner, and D. M. Krizman, "Curriculum innovation for simulation and design of wireless communications systems," *American Society Engineering Education Conf.*, June 1996. (CD ROM version only, location 162644ms.pdf.)

94. F. S. Cheng, P. Lemson, J. H. Reed, and I. Jacobs, "The dynamic range enhancement technique applied to an AMPS and CDMA cellular environment," *IEEE Veh. Technol. Conf. (VTC)*, April 1996, pp. 1057-1059.

95. M. Welborn and J. H. Reed, “Co-channel interference rejection using a model-based demodulator for AMPS and NAMPS,” *IEEE Veh. Technol. Conf. (VTC)*, April 1996, pp. 1312-1316.

96. M. Majmundar, J. H. Reed, and P. Petrus, “Interference rejection for IS-54 signals,” *IEEE Veh. Technol. Conf. (VTC)*, April 1996, pp. 1321-1325.

97. R. He and J. H. Reed, “A robust co-channel interference rejection technique for current mobile phone system,” *IEEE Veh. Technol. Conf. (VTC)*, April 1996, pp. 1007-1011.

98. T. E. Biedka, L. Mili, and J. H. Reed, “Robust estimation of the cyclic correlation in contaminated Gaussian noise,” *Asilomar Conf. Signals, Systems Computers*, November 1995, pp. 511-515.

99. R. He and J. H. Reed, “Spectral correlation of AMPS signals and its application to interference rejection,” *IEEE Military Commun. Conf. (MILCOM)*, October 1994, pp. 1007–1011 (Invited paper.)

100. V. Aue and J. H. Reed, “An interference robust CDMA demodulator that uses spectral correlation properties,” *IEEE Veh. Technol. Conf. (VTC)*, June 1994, pp. 563-567.

101. J. D. Laster and J. H. Reed, “A survey of adaptive single channel interference rejection techniques for wireless communications,” *Virginia Tech’s Fourth Annual Symposium Wireless Pers. Commun.*, June 1994, pp. 2.1-2.25. (Also *Wireless Personal Communications: Research Developments,* Kluwer Press, 1995.*)*

102. Howitt, J. H. Reed, V. Vemuri, and T. C. Hsia, “Recent developments in applying neural nets to equalization and interference rejection,” *Virginia Tech’s 3rd Annual Symposium Wireless Pers. Commun.*, June 1993, pp. 1.1-1.12. (Also *Wireless Personal Communications: Trends and Challenges,* Kluwer Press, 1994.)

103. B. G. Agee, K. Cohen, J. H. Reed, and T. C. Hsia, “Simulation performance of a blind adaptive array for a realistic mobile channel,” *IEEE Veh. Technol. Conf. (VTC)*, pp. 97-100.

104. J. H. Reed and B.G. Agee, “A technique for instantaneous tracking of frequency agile signals in the presence of spectrally correlated interference,” *Asilomar Conf. Signals, Systems, Computers*, 1992, pp. 1065-1071.

105. J. H. Reed and T. C. Hsia, “The theoretical performance of time-dependent adaptive filters for interference rejection,” *IEEE Military Commun. Conf. (MILCOM),* pp. 961-965*.*

106. R. Mendoza, J. H. Reed, T. C. Hsia, and B. G. Agee, “Interference rejection using a time-dependent constant modulus algorithm,” *Asilomar Conf. Signals, Systems Computers,* 1989, pp. 273-278.

107. J. H. Reed, C. D. Greene, and T. C. Hsia, “Demodulation of a direct sequence spread-spectrum signal using an optimal time-dependent receiver,” *IEEE Military Commun. Conf. (MILCOM)*, October 1989, pp. 657-662.

108. C. D. Greene, J. H. Reed, and T. C. Hsia, “An optimal receiver using a time-dependent adaptive filter,” *IEEE Military Commun. Conf. (MILCOM),* October 1989, pp. 650-666.

109. R. Mendoza, J. H. Reed, and T. C. Hsia, "Interference rejection using a hybrid constant modulus algorithm and spectral correlation discriminator," *IEEE Military Commun. Conf. (MILCOM),* October 1989, pp. 491-497.

110. J. H. Reed and T. C. Hsia, "Decision-directed demodulation," IEEE Conf. Decision Control, 1985, pp. 1286-1287.

111. J. H. Reed and T. C. Hsia, "Application of adaptive short-term correlation algorithms to interference rejection," Asilomar Conf. Signals, Systems, Computers, 1985, pp. 441-445.

112. J. H. Reed and T. C. Hsia, "A technique for separating short and long-duration signals and its application to interference rejection," 4th Yale Workshop Applications Adaptive System Theory, Yale University, 1985.

Papers, Talks, & Lectures Presented at Professional Meetings:

1. Mid Atlantic Broadband Corp. "Initiatives in Wireless Communications, April 2011

2. 66th Annual Meeting of the ORAU Council of Sponsoring Institutions, "The Hume Center", Oak Ridge TN, March 2011

3. Under invitation OSTP, "Testbed & Technology Platforms," White House Conference Center, Truman Room, Washington, DC January, 2011

4. Speaker, Oak Ridge National Laboratory Board of Governors, Oak Ridge, TN May 2010, "The Hume Center for National Security and Technology"

5. Keynote Presentation, "The Future of Cognitive Radio," Univ of Texas and Austin Technology Incubator. A group of faculty and VCs.

6. Invited Presentation, "The Second Wave of Wireless: A New Wave of Disruptive Technology," Atlantic Council (DC think-tank) to help inform international decision makers, Oct. 2010.

7. Cognitive Wireless Networking (CoRoNet), Keynote Speaker, Chicago, Illinois, September 20, 2010

8. The Ted & Karyn Hume Center Inauguration Reception and Board Meeting, Arlington, VA August 18, 2010.

9. NSF EARS Workshop, "Workshop on Enhancing Access To The Radio Spectrum', August 2010, Arlington, VA

10. Invited talk, "Cognitive Radio Research at VT," ISART, NTIA, July 2010.

11. DoD Technical Exchange Meeting at the Finnish Embassy under the aegis of the Secretary of Defense, Washington D.C. May 2010

12. Speaker, Oak Ridge National Laboratory Board of the Governors, May 2010

13. JASON, an independent group of scientists which advises the United States Governement on matters of science and technology - San Diego, CA May 2010

14. Dr. Jeffrey Reed and Dr. Nishith Tripathi, *Wireless Net Neutrality Regulation: A Response to Afflerbach and DeHaven, March 2010*, submitted to the FCC.

15. Jeffrey H. Reed & Nishith D. Tripathi, *The Application of Network Neutrality Regulations to Wireless Systems: A Mission Infeasible,* submitted to the FCC, Jan. 2010

16. Note the two reports above are *responses to the FCC Notice of Proposed Rule Making on Network Neutrality (a highly controversial subject that poses a major threat to the US wireless industry)*

17. "The Nexus of Security and Technological Leadership, Deemed Export Rule Recommendations and Zero-based Methods to Identify Technologies that Require Deemed Export Control', Submitted to the Security of Commerce by the Emerging Technologies and Research Advisory Committee, A Federal Advisory Committee Appointed by the Secretary of Commerce To examine EARS Regulations. 2009.
    Note current EARS regulations currently represent a major challenge to US industry and academia for engaging international personnel in research and this committee addressed this challenge.

18. Institute for Defense and Government Analysis Conference – Security Issues in Cognitive Radio, 2010.

19. Army Research Lab Seminar, Sept. 2009

20. Lectured VT-MENA in Alexandria, Egypt Nov. 2009

21. Technical seminar at Cairo University, Nov. 2009

22. Presented to NTIA, the telecom regulatory authority in Egypt, Nov. 2009

23. Korean US Communications Technology Symposium, July 2009

24. Finnish Embassy – US Military Collaboration with Finnish Government, March 10-11, 2008

25. Institute for Defense and Government Analysis Conference -- VT's Cognitive Radio and Security Research, March 2009

26. J. H. Reed, IEEE presentation to the IEEE San Diego Section, April 7, 2009 San Diego, CA.

27. J. H. Reed, "Distributed computing in collaborative software radio," presented to the Office of Naval Research, May 1, 2007.

28. J.H. Reed, Keynote Speaker at the *Communications Technology Program Review, Planning Assessment Meeting*, "Distributed computing for collaborative software defined radio," Naval Research Laboratory, May 2007.

29. J. H. Reed, "Issues in cognitive wireless networks," talk presented at the *Intel Research Forum Seminar Series*, Portland, OR, March 28, 2007.

30. J. H. Reed, "Issues in cognitive wireless networks," talk presented at NIST, March 2, 2007.

31. J. H. Reed, "Understanding the issues in software defined cognitive radios," seminar presented at the University of Pennsylvania, October 16, 2006.

32. J. H. Reed, "Issues in cognitive wireless networks," talk presented at the *IEEE Workshop Networking Technologies Software Defined Radio (SDR) Networks*, (held in conjunction with *SECON*), Reston, VA, September 25, 2006.

33. J. H. Reed, "Applications of Markov modeling to cognitive radio," presented at the *SASDCRT Conf.*, Naval Post Graduate School, Monterey, CA, September 12-13, 2006.

34. J. H. Reed, "Understanding the issues in software defined cognitive radios," seminar presented at Clemson University, SC, July 21, 2006.

35. J. H. Reed, "Understanding the issues in software defined cognitive radios," seminar presented at Kyung Hee University, Korea, June 12, 2006.

36. J. H. Reed, "Open architecture bridging the gap in emergency communications," guest speaker at the *International Wireless Communications Expo – IWCE Conf. Tektronix Symposium,* Las Vegas, NV, May 19, 2006.

37. J. H. Reed, "An introduction to cognitive radio and some research trends in cognitive radios," talk presented at *ETRI Cognitive Radio Workshop*, Seoul, Korea, April 2006.

38. J. H. Reed, S. Srikanteswara, and J. A. Neel, "Design choices for software radios," DVD tutorial. Available: http://sdrforum.org/store.html

39. Presentation titled "Software radio: The key for enabling 4G wireless networks," at the *International Forum - 4th Generation Mobile Commun.*, Centre for Telecommunications Research, May 2003.

40. J. H. Reed, "Key challenges in the design on software radios," workshop presented at *IDGA Software Radio Conf.*, Alexandria, Va., February 23, 2004.

41. J. H. Reed, "Issues in software radios," presented at Microsoft, Seattle, WA, March 3, 2003.

42. J. H. Reed, "Wireless convergence paradox," presented at *Samsung Telecom Forum*, Seoul, Korea, March 16-23, 2003.

43. W. H. Tranter, J. H. Reed, D. S. Ha, D. McKinstry, R. M. Buehrer, and J. Hicks, "High capacity communications using overloaded array," presented at *COMMTEC*, Chantilly, VA, September 16-20, 2002.

44. R. M. Buehrer and J. H. Reed, "Robust ad-hoc, short-range wireless networks for tracking and monitoring devices," presented to the Marine Corp., April 2002.

45. J. H. Reed, "Overloaded array processing with spatially reduced search joint detection," presented at the Dresden University of Technology, September 24, 2001.

46. J. H. Reed, Invited lecture series to several Korean companies, compliments of Samsung Advanced Institute of Technologies. The list of companies included: Samsung, LGIC, and ETRI. Spring 2000.

47. J. H. Reed, “The future of wireless,” invited talk, Atlantic City, NJ, November 15, 1999.

48. J. H. Reed, “Software radios,” *Motorola Futures Forum*, invited talk to corporate strategists, Pheonix, AZ, November 8, 1999.

49. P. Robert and J. H. Reed, “Digital video transmissions in a wireless system,” *9th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

50. M. Hosemann and J. H. Reed, “Synchronization techniques for spread spectrum signals,” *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

51. S. Srikanteswara and J. H. Reed, “Development of a software radio architecture using reconfigurable computing,” *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

52. J. Hicks, P. Roy, J. Tilki, L. Beex, J. H. Reed, and W. Farley, “Simulation tool for speech recognition over wireless,” *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

53. R. Ertel and J. H. Reed, “Optimum SINR antenna array performance analysis,” *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

54. R. Banerjee, B. D. Woerner and J. H. Reed, “Case studies in software radios,” *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

55. P. M. Robert, A. M. Darwish, and J. H. Reed, “Fast bit error generation for the simulation of MPEG-2 transmissions in wireless systems,” *IEEE Wireless Commun. Networking Conf.*, September 21-24, 1999. (Invited paper; proceedings on CD Rom.)

56. J. H. Reed and S. Srikanteswara, “Software radio architecture for a reconfigurable computing platform,” *IEEE Commun. Theory Workshop*, Aptos, CA, May 23-26, 1999.

57. R. Ertel , Z. Hu and J. H. Reed, “Antenna array vector channel modeling and data collection system,” *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

58. P. M. Robert and J. H. Reed, “Digital video transmissions in a wireless system,” *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

59. S. Swanchara, S. Srikanteswara, P. Athanas, and J. H. Reed, “Implementation of a multiuser receiver on a recongifugurable computing platform,” *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

60. Maheshware, et al., “Reconfigurable software radio,” *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

61. K. Phillips and J. H. Reed, “PDF estimation,” *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

62. N. Mangalvedhe and J. H. Reed, “Performane of reduced complexity algorithms in adaptive CDMA receivers,” *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

63. R. Mostafa and J. H. Reed, “Study of smart antenna as an interference rejection technique for the handset,” *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

64. N. Mangalvedhe and J. H. Reed, “Adapative receivers for multi-rate DS-CDMA systems,” *8th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1998. (Poster session.)

65. J. H. Reed and B. D. Woerner, "Analog to digital conversion and digital signal synthesis for software radios," half-day tutorial presented at the *IEEE 9th International Symposium Personal, Indoor, Mobile Radio Commun.*, Boston, MA, September 13-16, 1998. (Invited tutorial.)

66. J. H. Reed, “The software radio: Modern radio engineering,” Dresden University of Technology Guest Lecture, Dresden, Germany, November 25, 1997.

67. J. H. Reed, “Adaptive antenna arrays,” Dresden University of Technology Guest Lecture, Dresden, Germany, November 26, 1997.

68. J. H. Reed, “Overview of fundamental wireless systems in today’s telecommunications technology,” *46th Annual International Wire Cable Symposium*, Philadelphia, PA, November 17-20, 1997. (Invited tutorial.)

69. J. H. Reed and R. D. James, “Position location: Overview and business opportunities,” *Wireless Opportunities Workshop*, Roanoke, VA, October 22-23, 1997.

70. R. Ertel and J. H. Reed, “Geometrically based spatial channel models,” *7th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

71. A. Hannan and J. H. Reed, “GloMo radio API (application program interface,” *7th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

72. S. Swanchara, J. H. Reed, and P. Athanas, “Design and implementation of the GloMo multiuser receiver on a reconfigurable computing platform,” *7th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

73. N. D. Tripathi, J. H. Reed, and H. VanLandingham, “High performance handoff algorithms using fuzzy logic and neural networks,” *7th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

74. D. Breslin and J. H. Reed, “Multi-sensor testbed hardware development at the mobile and portable radio resesarch group,” *7th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

75. N. Mangalvedhe and J. H. Reed, “Blind CDMA interference rejection in multipath channels,” *7th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

76. K. Phillips, J. Laster, and J. H. Reed "Adaptive signal processing by bit error rate (BER) estimation," *7th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1997. (Poster session.)

77. T. S. Rappaport, J. H. Reed, and T. E. Biedka, "Position location & E-911: Techniques for wireless systems," *IEEE International Conf. Universal Pers. Commun.*, Cambridge, MA, October 1, 1996. (Invited tutorial.)

78. N. Tripathi and J. H. Reed, "DSP implementation of communications systems: An NSF sponsored curriculum development initiative," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

79. B. Fox, G. Aliftiras, I. Howitt, J. H. Reed, and B. D. Woerner, "Flexible hardware architectures for multimode wireless handsets," *Sixth 6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

80. P. Petrus and J. H. Reed, "Geometrically based statistical single bounce macrocell channel model for mobile environments," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session; also in *IEEE Smart Antennas: Adaptive Arrays, Algorithms, & Wireless Position Location*, 1998, pp. 483-487.)

81. GloMo team, "GloMo adaptive antenna array research," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

82. GloMo team, "GloMo mobile yser research," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

83. J. D. Laster and J. H. Reed, "Improved GMSK demodulation using non-coherent receiver diversity," *Sixth 6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

84. K. Khan, J. H. Reed,and I Howitt, "Interference mitigation in AMPS/NAMPS and CMP using artificial neural networks," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

85. N. Tripathi, J. H. Reed, and H. VanLandingham, "Neural net & fuzzy logic approaches to handoffs in cellular systems," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

86. K. Saldanha and J. H. Reed, "Performance evaluation of an AMPS digital base station with automatic gain control," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

87. R. He and J. H. Reed, "System capacity improvement by ysing DSP interference rejection techniques," *6th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1996. (Poster session.)

88. B. D. Woerner, T. S. Rappaport, and J. H. Reed, "Improved spectral efficiency for CDMA systems," *Wireless Technology Conf. Exposition Proceedings*, Stamford, CT, September 1995.

89. P. Petrus and J. H. Reed, "New blind multichannel filtering techniques," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

90. N. Zecevic and J. H. Reed, "Comparative study of adaptive CDMA interference rejection techniques," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

91. M. Majmundar and J. H. Reed, "Interference rejection for IS-54," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

92. D. Bailey and J. H. Reed, "MPRG: Signal processing and communications laboratory," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

93. R. He and J. H. Reed, "Co-channel interference for AMPS and NAMPS signals," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

94. N. Mangalvedhe and J. H. Reed, "An Eigenstructure technique for soft synchronization of DSSS signals," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

95. M. Welborn and J. H. Reed, "Interference rejection using model-based spectral estimation," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

96. A. Amanna, R. James, and J. H. Reed, "Communications on the smart road," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

97. F. Dominique and J. H. Reed, "Development of a frequency hopping system for the 902-928 MHz ISM band," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

98. S. Elson and J. H. Reed, "Modeling CDPD," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.).

99. P. Petrus, F. Dominique, and J. H. Reed, "Spectral redundancy exploitation in narrowband interference rejection for a PN-BPSK system," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

100. F. Cheng and J. H. Reed, "Dynamic range enhancement techniques for RF and fiber optic interface," *5th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1995. (Poster session.)

101. P. Petrus and J. H. Reed, " Blind adaptive arrays for mobile communications," *4th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1994. (Poster session.)

102. R. He and J. H. Reed, "Spectral correlation of AMPS signals with applications to interference Rrejection," *4th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1994. (Poster session.)

103. R. Zheng and J. H. Reed, "System modeling and interference rejection for spread spectrum CDMA automatic vehicle monitoring systems," *4th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1994. (Poster session.)

104. N. Mangalvedhe and J. H. Reed, “An eigenstructure technique for soft spread spectrum synchronization,” *4th Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1994. (Poster session.)

105. R. Holley and J. H. Reed, “Time-dependent filters For CDMA interference rejection,” *3rd Annual Symposium Wireless Pers. Commun.*, Virginia Tech, June 1993. (Poster session.)

Technical Reports:

1. Y. Zhao, “Enabling cognitive radios through radio environment maps,” MPRG-TR-07- Ph.D. dissertation, May 2007.

2. R. Menon and J. H. Reed, “Interference avoidance based underlay techniques for dynamic spectrum sharing,” MPRG-TR-07-, Ph.D. dissertation, April 2007.

3. J.-H. Kim and J. H. Reed, “On the impact of MIMO implementations on cellular networks: An analytical Aapproach from a system perspective,” MPRG-TR-07-, Ph.D. dissertation, March 2007.

4. R. Chembil Palat and J. H. Reed, “Performance analysis of cooperative communications for wireless networks,” MPRG-TR-06-, Ph.D. dissertation, December 2006.

5. J. O. Neel and J. H. Reed, “Analysis and design of cognitive radio networks and distributed radio resources management in algorithms,” MPRG-TR-06-14, Ph.D. Dissertation, September 2006.

6. C. R. Anderson and J. H. Reed, “A software defined ultra wideband transceiver testbed for communications, ranging, and imaging,” MPRG-TR-06-13, Ph.D. dissertation, September 2006.

7. C. R. Anderson, S. Venkatesh, D. Agarwal, R. Michael Buehrer, P. Athanas, and J. H. Reed, “Time interleaved sampling of impulse ultra wideband signals: Design challenges, analysis, and results,” MPRG-TR-06-12, technical report, August 2006.

8. J.-H. Kim and J. H. Reed, “Efficacy of transmit smart antenna at mobile station in cellular networks,” MPRG-TR-06-09, Ph.D. preliminary, May 2006.

9. J. A. DePriest and J. H. Reed, “A practical approach to rapid prototyping of SCA waveforms,” MPRG-TR-06-06, M.S. thesis, April 2006.

10. B. M. Donlan, R. M. Buehrer, and J. H. Reed, “Ultra-wideband narrowband interference cancellation and channel modeling for communications,” MPRG-TR-05-02, M.S. thesis, January 2005.

11. S. Vasudevan and J. H. Reed, “A simulator for analyzing the throughput of IEEE 802.11b wireless LAN systems,” MPRG-TR-05-01, M.S. thesis, January 2005.

12. A. M. Hebbar and J. H. Reed, “Empirical approach for rate selection in MIMO OFDM,” MPRG-TR-04-11, M.S. thesis, December 2004.

13. C. R. Anderson, A. M. Orndorff, R. M. Buehrer, and J. H. Reed, "An introduction and overview of an impulse-radio ultrawideband communication system design," MPRG_TR-04-07, technical report, May 2004.

14. J. Hicks and J. H. Reed, "Novel approaches to overloaded array processing," MPRG-TR-03-19, Ph.D. dissertation, August 2003.

15. R. Mostafa and J. H. Reed, "Feasibility of smart antennas for the small wireless terminals," MPRG-TR-03-12, Ph.D. dissertation, April 2003.

16. S. Krishnamoorthya and J. H. Reed, "Interference measurements and throughput analysis for 2.4 GHz wireless devices in hospital environments," MPRG-TR-03-10, M.S. thesis, April 2003.

17. P. M. Robert and J. H. Reed, "Reduction in coexistent WLAN interference through statistical traffic management, MPRG-TR-03-09, Ph.D. dissertation, April 2003.

18. W. G. Newhall and J. H. Reed, "Radio channel measurements and modeling for smart antenna array systems using a software radio receiver," MPRG-TR-03-08, Ph.D. dissertation, April 2003.

19. Y. Ahmed and J. H. Reed, "A model-based approach to demodulation of co-channel MSK signals," MPRG-TR-02-24, M.S. thesis, December 2002.

20. R. Chembil Palat and J. H. Reed, "VT-STAR design and implementation of a test bed space-time block coding and MOMI channel measurements," MPRG-TR-02-19, M.S. thesis, October 2002.

21. W. Newhall and J. H. Reed, "Radio channel measurements, modeling, and characterization for antenna array Ssystems," MPRG-TR-02-16, Ph.D. preliminary, August 2002.

22. B.-L. Cheung and J. H. Reed, "Simulation of adaptive array algorithms for OFDM and adaptive vector OFDM systems," MPRG-TR-02-15, M.S. thesis, September 2002.

23. R. Mostafa, R. Gozali, W. Newhall, I. Akbar, J. H. Reed, B. D. Woerner, and W. H. Tranter, "Navy collaborative integrated information technology initiative," report #19, MPRG-TR-02-13, technical report, April 2002.

24. R. Mostafa, R. Gozali, W. Newhall, I. Akbar, J. H. Reed, B. D. Woerner, and W. H. Tranter, "Navy collaborative integrated information technology initiative," report # 17, MPRG-TR-02-05, technical report, January 2002.

25. S. Marikar, L. DaSilva, and J. H. Reed, "Resource management in 3G systems employing smart antennas," MPRG-TR-02-04, M.S. thesis, January 2002.

26. P. M. Robert and J. H. Reed, "Reduction in coexistent WLAN interference through statistical traffic management," MPRG-TR-02-01, Ph.D. preliminary, August 2001.

27. R. Mostafa, R. Gozali, W. Newhall, I. Akbar, J. H. Reed, B. D. Woerner, and W. H. Tranter, "Navy collaborative integrated information technology initiative," report # 16, MPRG-TR-01-17, technical report, October 2001.

28. M. Soni, P. Athanas, and J. H. Reed, "Computing engine for reconfigurable software radio," MPRG-TR-01-15, M.S. thesis, October 2001.

29. T. E. Biedka and J. H. Reed, “Analysis and development of blind adaptive beamforming algorithms,” MPRG-TR-01-14, Ph.D. dissertation, August 2001.

30. R. Gozali, R. Mostafa, P. M. Robert, R. Chembil Palat, W. Newhall, B. D. Woerner, and J. H. Reed, “Design process of the VT-STAR multiple-input multiple-output (MIMO) test bed,” MPRG-TR-01-12, technical report. August 2001.

31. R. Mostafa, R. Gozali, W. Newhall, I. Akbar, J. H. Reed, B. D. Woerner, and W. H. Tranter, “Navy collaborative integrated information technology initiative,” report # 15, MPRG-TR-01-11, technical report, July 2001.

32. S. Srikanteswara and J. H. Reed, “Design and implementation of a soft radio architecture for reconfigurable platforms,” MPRG-TR-01-10, Ph.D. dissertation, July 2001.

33. R. Mostafa and J. H. Reed, “Feasibility of transmit smart antenna at the handset,” MPRG-TR-01-07, Ph,D. preliminary, December 2000.

34. J. Hicks and J. H. Reed, “Overloaded array processing with spatially reduced search joint detection,” MPRG-TR-00-08, M.S. thesis, May 2000.

35. T. Biedka and J. H. Reed, “A general framework for the analysis and development of blind adaptive algorithms,” MPRG-TR-OO-O5, Ph.D. preliminary, April 2000.

36. S. Srikanteswara and J. H. Reed, “Design and implementation of a soft radio architecture for reconfigurable platforms,” MPRG-TR-00-02, Ph.D. preliminary, November 1999.

37. R. B. Ertel and J. H. Reed, "Antenna array systems: Propagation and performance,” Ph.D. dissertation, July 1999.

38. N. R. Mangalvedhe and J. H. Reed, “Development and analysis of adaptive interference rejection techniques for direct sequence code division multiple access systems,” Ph.D. dissertation, July 1999.

39. K. Phillips and J. H. Reed, “Probability density function estimation for minimum bit error rate equalization,” MPRG-TR-99-04, M.S. thesis, May 1999.

40. Z. Hu and J. H. Reed, “Evaluation of joint AOA and DOA estimation algorithms using the antenna array systems,” MPRG-TR-99-02, M.S. thesis, December 1998.

41. R. B. Ertel and J. H. Reed, "Antenna array systems: Propagation and performance," MPRG-TR-98-12, Ph.D. preliminary, December 1998.

42. N. R. Mangalvedhe and J. H. Reed, "Development and analysis of adaptive interference rejection techniques for direct sequence code division multiple access systems," MPRG-TR-98-13, Ph.D. preliminary, December 1998.

43. P. M. Robert and J. H. Reed, "Simulation tool and metric for evaluating wireless digital video systems," MPRG-TR-98-11, M.S. thesis, September 1998.

44. S. F. Swanchara and J. H. Reed, “An FPGA-based multiuser receiver employing parallel interference cancellation,” MPRG-TR-98-06, M.S. thesis, July 1998.

45. N. Tripathi and J. H. Reed, “Generic handoff algorithms using fuzzy logic and neural networks,” Ph.D. dissertation, MPRG-TR-97-18, November 1997.

46. D. Breslin and J. H. Reed, “Adaptive antenna arrays applied to position location,” MPRG-TR-97-14, M.S. thesis, August 1997.

47. S. Nicoloso and J. H. Reed, “Investigation of carrier recovery techniques for PSK modulated signals in CDMA and multipath mobile environments,” MPRG-TR-97-11, M.S. Thesis, May 1997.

48. N. Tripathi, J. H. Reed, and H. VanLandingham, “An adaptive direction biased fuzzy handoff algorithm with unified handoff candidate selection criterion,” MPRG-TR-97-08, April 1997.

49. N. Tripathi, J. H. Reed, and H. VanLandingham, “An adaptive algorithm using neural encoded fuzzy logic system,” MPRG-TR-97-07, April 1997.

50. N. Tripathi, J. H. Reed, and H. VanLandingham, “A new class of fuzzy logic based adaptive handoff algorithms for enhanced cellular system performance,” MPRG-TR-97-06, April 1997.

51. B. Fox and J. H. Reed, “Analysis and dynamic range enhancement of the analog-to-digital interface in multimode radio receivers,” MPRG-TR-97-02, February 1997.

52. A. Alexander, S. Panchapakesan, D. Breslin, J. H. Reed, T. Pratt, and B. D. Woerner, “The feasibility of performing TDOA based position location on existing cellular infrastructures,” MPRG-TR-96-37, December 20, 1996.

53. N. Tripathi and J. H. Reed, “Handoffs in cellular systems: A tutorial,” MPRG-TR-96-35, November 1996.

54. N. Zecevic and J. H. Reed, “Interference rejection techniques for the mobile unit direct-sequence CDMA receiver,” MPRG-TR-96-27, August 1996.

55. K. J. Saldanha and J. H. Reed, “Performance evaluation of DECT in different radio environments,” MPRG -TR-96-28, August 1996.

56. R. He and J. H. Reed, “AMPS co-channel interference rejection techniques and their impact on system capacity,” MPRG-TR-96-25, July 1996.

57. N. Zecevic and J. H. Reed, “Techniques and adaptation algorithms for direct sequence spread spectrum capacity,” MPRG-TR-96-27, July 1996.

58. M. K. Khan, J. H. Reed, and I. Howitt, “Interference mitigation in AMPS/NAMPS and GSM using artificial neural networks,” MPRG-TR-96-24, June 1996.

59. J. H. Reed, T. S. Rappaport, and B. D. Woerner, “What you should know before returning to school,” *RF Design*, pp. 67-69, March 1996.

60. T. Biedka and J. H. Reed, “Direction finding methods for CDMA mobile wireless systems,” MPRG-TR-96-20, June 1996.

61. Y. M. Vasavada and J. H. Reed, “Performance evaluation of a frequency modulated spread-spectrum system,” MPRG-TR-96-13, February 1996.

62. M. V. Majmundar and J. H. Reed, "Adaptive single-user receivers for direct sequence CDMA systems," MPRG-TR-96-12, January 1996.

63. R. He and J. H. Reed, "Co-channel interference rejection techniques for AMPS signals using spectral correlation characteristics," MPRG-TR-96-11, January 1996.

64. J. S. Elson and J. H. Reed, "Simulation and performance analysis of cellular digital packet data," MPRG-TR-96-08, February 1996.

65. J. D. Laster and J. H. Reed, "Improved GMSK demodulation emphasizing single channel interference rejection techniques," MPRG-TR-96-05, February 1996.

66. M. Welborn and J. H. Reed, "Co-channel interference rejection using model-based demodulator" MPRG-TR-96-04, January 1996.

67. F. Dominique and J. H. Reed, "Design and development of a frequency hopper based on the DECT system for the 902-928 MHz ISM band," MPRG-TR-96-02, January 1996.

68. P. Athanas, I. Howitt, T. S. Rappaport, J. H. Reed, and B. D. Woerner, "A high capacity adaptive wireless receiver implemented with a reconfigurable computer architecture," MPRG-TR-18, November 1995.

69. N. Mangalvedhe and J. H. Reed, "An eigenstructure technique for direct sequence spread spectrum synchronization," MPRG-TR-95-04, April 1995.

70. Y. M. Kim, N. Mangalvedhe, B. D. Woerner, and J. H. Reed, "Development of a low power high data rate spread-spectrum modem," MPRG-PPR-95-01, February 1995.

71. Y. M. Kim, N. R. Mangalvedhe, B. D. Woerner, and J. H. Reed, "Development of a low power high data rate spread-spectrum modem," MPRG-PPR-95-02, June 1995.

72. P. Petrus and J. H. Reed, "Blind adaptive antenna arrays for mobile communications," MPRG-TR-95-01, December 1994.

73. S. Yao and J. H. Reed, "Differential detection of GMSK signals," MPRG-TR-94-27, October 1994.

74. R. Zheng, J. Tsai, R. Cameron, L. Beisgen, B. D. Woerner, and J. H. Reed, "Capacity and interference resistance of spread-spectrum automatic vehicle monitoring systems in the 902-928 MHz ISM Band," MPRG-TR-94-26, final report to Southwestern Bell Mobile Systems, October 1994.

75. F.-S. Cheng and J. H. Reed, "A new approach to dynamic range enhancement," MPRG-TR-94-25, October 1994.

76. R. S. Zheng and J. H. Reed, "Channel modeling and interference rejection for CDMA automatic vehicle monitoring systems," MPRG-TR-94-21, November 1994.

77. R. He and J. H. Reed, "AMPS interference rejection: Blind time-dependent adaptive filtering - Volume I," final report to ARGO Systems Inc., MPRG-TR-94-19, July 1994.

78. T. H. Qazi and J. H. Reed, "Model-based demodulation of FM signals - Volume II," MPRG-TR-94-17, final report to ARGO Systems, August 1994.

79. M. Subramanian and J. H. Reed, "Noncoherent spread-spectrum communication systems," MPRG-TR-94-14, August 1994.

80. F. Cheng, A. Kelkar, I. Jacobs, and J. H. Reed, "Performance evaluation for the dynamic range enhancement technique (DRET)," MPRG-TR-94-10, final report to Southwestern Bell Technology Resources, September 1994.

81. V. Aue and J. H. Reed, "Optimum linear single user detection in direct-sequence spread-spectrum multiple access systems," MPRG-TR-94-03, March 1994.

82. R. Holley and J. H. Reed, "Time dependent adaptive filters for interference cancellation in CDMA systems," MPRG-TR-93-15, September 1993.

Other Papers & Reports:

1. P. M. Robert and J. H. Reed, "Va. Tech finds soft radio's missing link," *EE Times*, August 2004.

2. J. H. Reed, T. C. Hsia, and H. Etemad, "Differential demodulation of BPSK using time dependent adaptive filtering," final report to California MICRO Program, 1992.

3. J. H. Reed, "Adaptive filters and their application to interference rejection," *Defense Electronics*, pp. 85-86 and 89-90, May 1989.

4. W. Gardner, B. G. Agee, W. A. Brown, C. K. Chen, J. H. Reed, and R. S. Roberts, "A comparison of Fourier transformation and model fitting methods of spectral analysis," Signal and Image Processing Lab Report No. SIPL-86-4, Department of Electrical and Computer Engineering, University of California, Davis, 1986. (Also in *Statistical Spectral Analysis — A Non Probabilistic Theory*, Prentice-Hall.)

Selected Corporate Report Topics:

* A DSP-Based Receiver for the New North American Digital Cellular Standard
* Spread Spectrum Detection Techniques
* Cyclic Spectral Analysis of Modulated Signals
* Projection of Future High-Volume Digital Communication Systems
* A High Speed Digital Filter for Sample Rate Conversion
* A Least-Squares System Identification Method
* Cyclic Adaptive Filtering for Interference Rejection
* Implementation Issues of Adaptive Interference Rejection Techniques
* Investigation of Modern Spectral Analysis Techniques
* The Performance of Time-Dependent Adaptive Filtering of Real Data
* A Maximum-Likelihood Estimator for Tracking and Detecting Frequency Hopping Signals

* Digital Signal Processing Algorithms for Squelch Control
* A Low-Cost Whitening Filter for Jammer Applications
* Time-Dependent Single Channel and Multi-Channel Interference Rejection Algorithms

Section V. Public Service/Outreach

Industrial Affiliate/Outside Agency Contacts:

Companies and Government Agencies visited in 2009 - 2012 to promote Wireless@ VT and the Hume Center:

Apple Computer
Booz Allan Hamilton
DARPA
Army Research Lab
ZETA
SAIC
DRT
Laboratory of Telecommunications Science
John Hopkins Applied Physics Lab
NRO
NSA
CRT
Defense Spectrum Office
NIST
NRL
Northrup Grumman
ISI
RINCOM
CERDEC
Award Solution
ONR
Applied Signal Technologies
DSO
GE
MBC
LTS
Nokia
IDA
Motorola
NSA
MA-COMM
Intel
NSF
FCC
FBI
Samsung
Aerospace Corporation
CIA
US Army
Thales Communications
Textronix
ONR
SPAWAR
ATT
Ventura Solutions
Syracuse Research Corp
SPAWAR
I-APRA
L-3
DRS
CAER
Lockheed Martin

Funding Agency Reviewer:

NSF
University of California, MICRO
Kansas 2000
Qtar Science Foundation
ARO
Canadian Foundation for Innovation

Sponsored Visiting Researchers:

Ahmed Darwish from Cairo University, June-September 1999
Yeongjee Chung from Korea, January-August 1999
Shinichi Miyamoto from Kobe, Japan, April 2001-March 2002
Young-Soo Kim from Seoul, Korea, February 2002-February 2003
Friedrich Jondral from Karlsruhe, Germany, April-June 2004
Francisco Portelinha from Brazil, October 2004-February 2006
Seuck Ho Won from Korea, February 2005-January 2006
Duk Kyu Park from Seoul South Korea, January 2007-February 2008
Marojevic Vuk from Spain, September 2007-January 2008
Francisco Martins Portelinha from Brazil, February 2008-March 2008
Jeong Ho Kim from South Korea, July 2008 – February 2010
Stefan Werner Nagel from Germany, August 2009 - October 2009
Arthur Herzog from Darmstadt, Germany April 2010 – June 2010

Conference Organization & Technical Reviewing:

Editorial Board Member for the Proceedings of the IEEE
IEEE Fellows Selection Committee for Computer Society
Organizing Committee for Globecom 2010
Technical Program Committee for IEEE Dyspan 2009/2010
Technical Program Committee for Globecomm 2009
Technical Program Committee for VTC 2009
Technical Program Committee for COMCAS 2009 (and session chair)
Associate Editor for Proceedings of the IEEE, Issue on Cognitive Radio, April & May 2009
Associate Editor for IEEE Journal on Select Area of Communications, Issue on Cognitive Radio
Technical Program Committee for IEEE Conference on Communications
Technical Program Committee for CrownCom
Reviewer

IEEE Transactions on Antennas and Propagation
IEEE Transactions on Wireless Communications
IEEE Transactions on Communications
IEEE Transactions on Signal Processing
IEEE Transactions on Aerospace and Electronics Systems
IEEE Transactions on Selected Areas of Communications
IEEE Signal Processing Letters
IEEE Communications Magazine
IEEE Communications Letters
International Journal of Electronics

Session Chair for the SDR Forum 2007, Denver, CO, November 5 – 9, 2007
Advisory Board, *IEEE International Conf. Ultrawideband (ICU)*, September 2005.
Moderator for the paper session “Ultrawideband Design Approaches,” at the *Communications Design Conf.*, March - April 2004.
Moderator for the panel, “UWB Panel on Communication Systems Design,” at the *Communications System Design Conf.*, October 2003.
Chair of session titled, “Mobile Computing and Software Defined Radios,” at the *International Conf. Engineering Reconfigurable Systems Algorithms (ERSA)*, June 2003.
Co-technical program chairman for the *SDR Forum Conf.*, November 2002.

General Chair for the *UWBST Conf.*, November 2003.
Technical program chairman for the *SDR Forum/MPRG Workshop Smart Antennas*, June 2003.

Federal & State:

President's Council of Advisors in Science and Technology working group on transitioning federal spectrum for commercial use and economic growth, 2011-2012

Army Research Office Board of Visitors, 2012- present

Idaho National Labs Advisory Board, 2012 - present

IEEE Fellows Evaluation Committee for Computer Science, 2012

National Science Foundation workshop co-organizer, *Enhancing Access to the Radio Spectrum*, August, 2010. Goal was to develop a major research program to support spectrum research for the National Broadband Plan. Participants include Secretary of Commerce, a Commissioner of the FCC, interim head of NSF, multiple NSF Division Directors, Whitehouse and Capitol Hill staffers.

US Dept. of Commerce Committee on EARS Regulations 2008-2009. A Federal Advisory Committee Appointed by the Secretary of Commerce To examine EARS Regulations. 2009. *Note current EARS regulations currently represent a major challenge to US industry and academia for engaging international personnel in research and this committee addressed this challenge.* 2007.

Co-Leader for the SDR Forum and Object Management Group of Smart Antenna API standardization efforts 2008-2009

Co-Leader for NSF workshop on SDR held in Ireland on May 12 – 16, 2008.

Virginia Broadband Task Force (headed by now Senator Warner and US CTO Anish Chopra) to examine steps for bridging the digital divide.

DARPA panel member to identify and create new programs for DARPA to support NSA. This activity is expected to result in $60M – $80M in new DARPA programs. 2007

Workshop help DARPA define a new program in bio-mimesis, the imitation of living organisms through electronics and mechanics.

Assisted the Army Research Office in developing their five year research plan forcommunications.

University Professional Service Current & Past:

Distinguished Lecturer for the IEEE Vehicular Technology
Director Wireless @ Virginia Tech
Interim Director, Ted and Karyn Hume Center
Participation within the Center for Wireless Telecommunications (CWT)
Department Computing Committee
Faculty Advisor to the Honor System

Faculty Advisory Committee, Information Technology for VT
EE Graduate Administrative Committee (Grad AdCom)
Communications Area Committee
US Student Recruitment Strategy Task Force
Course supervisor of ECPE 5674 and ECPE 4654
ECE Department Head Search Committee
ECE Executive Committee
ECE Resource Committee
Deputy Director, MPRG
ECE Recruiting Committee

Section VI. Industrial Experience

Industrial Employment:

Allied Communications, co-founder, 2011- present
Power Fingerpring, Inc. President and Co-Founder, 2011-Present
Cognitive Radio Technology, LLC. CTO and co-founder, 2007- Present
Co-founded Dot Mobile, Inc. March 2000-2001
(Company specializes in mobile data applications including wireless-internet based applications.)

Past Clients

ACM Systems	Grass Valley Group
Analog Devices	BRTRC
DIGCOM	E-Systems
F&S	General Dynamics
Gray Cary	Harris Broadband
Honeywell	HRL
IWT	Jones Day
NORCOMM	SAIC
Labarge	IDA
SRC	Weil
Samsung	MITRE
Shafer	SCA Technica
IIT	Navsys
US Navy	Tantivy
Arnold Porter	Sidley Austin

Founded Reed Engineering, March 1986 – Present
(Company performs consulting, expert witnessing and training in wireless communications and signal processing.)

Member, Technical Staff Signal Science, Inc., Santa Clara, CA, 1980-1985

Areas of Specialization:

- Spread spectrum detection
- Foreign technology analysis
- Computer systems administration

Past and Current Advisory Board Positions:

TechContinuum
Samsung Telecommunications
Spyrock
Totus Lighting
Airbee
FAWNA
Wayve Tech

Selected past industry projects:

- Technical Evaluation of AT&T and T-Mobile Merger
- Comments on FCC NPR making
- Expert Witness Wireless Email
- Software Architecture for Radios
- Company acquisition evaluation
- Expert witness in wireless location systems (multiple times)
- Evaluation of a wireless high-speed internet access system
- Evaluation of wireless/signal processing companies for acquisition
- Tutorials on software radio issues
- Tutorials on trends in wireless communications
- Adaptive interference rejection techniques
- Spread spectrum signal detection
- Expert witness for wireless power sources
- Study Panelist for NSA/DARPA programs via Schafer Corp.
- Advising on Trends in Communications: SAIC
- Provide Survey of Low Power Communications Trends: Mitre Corporation

ATTACHMENT B

(Professor Tripathi CV)

Nishith D. Tripathi, Ph. D.
419 Stonebridge Circle, Allen, TX 75013
Tel.: 214-477-3516 and E-mail: ntripathi123@att.net

AREAS OF EXPERTISE

LTE (E-UTRAN and EPC), LTE-Advanced, IMS, WiMAX, 1xEV-DO (Rev. 0 and Rev. A), UMTS R99, HSDPA, HSUPA, HSPA+, CDMA2000 1xRTT, IS-95, CDMA, OFDM, OFDMA, Advanced Antenna Technologies, IP-related Technologies

PUBLICATIONS

- Author of an upcoming **book** (with Jeffrey H. Reed), "Cellular Communications: A Comprehensive and Practical Guide," ***Accepted for Publication by IEEE/Wiley***, 2013. (**Book Contents**: Introduction to Cellular Communications, Elements of a Digital Communication System, Radio Propagation, IP Fundamentals, GSM, GPRS, EDGE, IS-95, CDMA2000 1xRTT, R99 UMTS/WCDMA, 1xEV-DO Rev. 0, HSDPA, 1xEV-DO Rev. A, HSUPA, HSPA+, IMS, Emerging 4G Technologies)
- Author of a **book** (with Jeffrey H. Reed and Hugh F. VanLandingham), "Radio Resource Management in Cellular Systems," Kluwer Academic Publishers, 2001.
- Contributor (With Jeffrey H. Reed) to the article, "Technical Challenges in Applying Network Neutrality Regulations to Wireless Systems," in the **book** titled "Net Neutrality: Contributions to the Debate," Edited by Jorge Perez Martinez, 2011.
- Author of one chapter in the **book**, "Neuro-Fuzzy and Fuzzy-Neural Applications in Telecommunications," Editor- Peter Stavroulakis, Springer, April 2004.

EXPERIENCE

AWARD SOLUTIONS *March '04 to Present*

Director and Principal Consultant

- Successfully launched a new program to ensure and develop SME (Subject Matter Expert) expertise in the areas of LTE RAN and Ethernet-based Backhaul. Developed processes and plans to facilitate SME certification. Devised expertise development plans, on-line tests, and defense tests. Directed the oral defense meetings for the final stage of SME certification.
- Managed and led SMEs for following course development projects: LTE Bootcamp-Phase II (**Topics**: End-to-end Data Sessions in LTE-EPC, PCC: QoS and Charging Architecture for LTE, Voice over LTE (VoLTE) using IMS, Voice services using CSFB and SRVCC, LTE and eHRPD Interworking, LTE and GSM/UMTS interworking, and LTE-Advanced), and LTE Radio Network Planning and Design.
- Mentored SMEs to prepare them to teach technologies such as LTE, WiMAX, OFDM, and Advanced Antennas.
- Developed courses on LTE-Advanced and TD-LTE.
- Developed two sessions, TD-LTE and Self Organizing Network (SON), as part of LTE Bootcamp- Phase II for an infrastructure vendor.
- Enhanced the LTE Radio Network Planning and Design course to reflect configurations of commercial deployments using LTE log-files and to adhere to customer-specific RF design guidelines.
- Continued to teach a variety of LTE and HSPA+ courses (e.g., VoIP, IMS, and IPv6 for LTE and HSPA+ Signaling) at new and existing clients.
- Delivered several web-based sessions of LTE Bootcamp- Phase II.

Lead SME

- Taught *first-time offerings* of courses at various clients to acquire new training business.
- Managed and guided SMEs for timely and quality-controlled completion of following course development projects: LTE/1xEV-DO Interworking, EPC Overview, HSPA+

Overview, Fundamentals of RF Engineering, IP Convergence Overview, and Advanced Antenna Techniques.

- Devised and implemented strategies to maximize the quality of project deliverables and to accelerate the completion of the deliverables.

SME- Course Development

- Developed an in-depth LTE Bootcamp Series for an infrastructure vendor (**Topics**: EPS Network Architecture, OFDMA/SC-FDMA, Radio Channels, System Acquisition & Call Setup, DL & UL Traffic Operations, Handover, and Antenna Techniques).
- Developed numerous instructor-led and web-based training courses by working in a team environment (**Examples**: Interworking of LTE with 1xEV-DO & 1xRTT, LTE Air Interface, WiMAX Essentials, WiMAX Network Planning, UMB, 1xEV-DO, HSUPA, Multiple Antenna Techniques, and IP Convergence).
- **Example Course Contents**: Network architecture, air interface features, DL & UL data transmission, call setup, handover/handoff, resource management, and interworking.
- Designed outlines for several new courses.

Senior Consultant- Training

- Taught *in-person* and *web-based* (via WebEx and LiveMeeting) courses at major chip-set manufacturers, infrastructure & device vendors, service operators, and test-tool vendors.
- Delivered an in-depth LTE bootcamp multiple times for a major LTE infrastructure vendor.
- **Area Expertise**: LTE Radio Network Planning & Design (including Certification), Interworking of LTE with (1xEV-DO, 1xRTT, UMTS, and GERAN), LTE Protocols & Signaling, LTE Air Interface, WiMAX Networks and Signaling, 1xEV-DO Optimization, 1xEV-DO Rev. 0 and Rev. A, IP Fundamentals, HSDPA/HSUPA/HSPA+, UMTS R4/R5 Core Networks, UMTS Network Planning and Design
- Strived to make the training experience full of *relevant* knowledge and to maximize the value of training to students.

VIRGINIA TECH *Spring 2010 to Present*

Adjunct Assistant Professor

- Co-taught the cellular communications class.
- Developed and presented the lecture material. Designed and graded quizzes.
- Helped educate the NSF about LTE and LTE-Advanced.

HUAWEI TECHNOLOGIES *October '01 to March '04*

Product Manager and Senior Systems Engineer

- Worked with engineers to resolve numerous **field trial issues** for **CDMA2000** systems.
- Defined test procedures for various features to evaluate performance of the CDMA2000 product.
- Designed advanced RL MAC and Power Control algorithms for a 1xEV-DO System.
- Designed various high-performance radio resource management (RRM) algorithms for the **CDMA2000** base station and base station controller. Major designed features include adaptive forward link and reverse link call admission control algorithms, dynamic F-SCH rate and burst duration assignment algorithms, R-SCH rate assignment algorithm, F-SCH burst extension and termination mechanisms, schedulers, forward link and reverse link overload detection and control algorithms, SCH soft handoff algorithm, F-SCH power control parameter assignment mechanism, adaptive radio configuration assignment algorithm, load balancing algorithm, and cell-breathing algorithm.
- Worked on the design of an RRM simulator to evaluate the performance of call admission control, load control, and scheduling algorithms for a **CDMA2000** system.
- Designed system level and network level simulators to evaluate the capacity gain of the smart antenna-based **UMTS** systems employing multiple beams.

- Reviewed **UMTS** RRM design and proposed enhancements related to call admission control, cell breathing, load balancing, soft capacity control, potential user control, and AMR control.
- Educated engineers through presentations to facilitate development of the **1xEV-DO** product.
- Led a team of engineers to define a comprehensive **simulation tool-set** consisting of link level simulator, system level simulator, and network level simulator to evaluate performance of CDMA systems including **IS-95**, **IS-2000**, **1xEV-DO**, **1xEV-DV**, and **UMTS**.
- Managed a group of engineers, prepared project plans, and established efficient processes to meet the requirements of the **CDMA2000** BSC product line.

NORTEL NETWORKS *September '97 to September '01*

Senior Engineer

Radio Resource Management, July '99 to Sept. '01

- Developed a comprehensive RRM simulator that models data traffic and major features of the MAC layer and physical layer. Analyzed various aspects of the RRM for several test cases. The performance results such as capacity and throughput were used in educating the service providers on the RRM for IS-2000 systems.
- Proposed a generic call admission control algorithm and filed a patent with the U.S. Patent Office.

Management of Supplemental Channels, June '00 to Sept. '01

- Designed and analyzed supplemental channel management for enhanced data performance and filed a patent with the U.S. Patent Office.

Data Traffic Modeling, Jan. '99 to Sept. '01

- Prepared a common framework for data traffic models for analysis of systems carrying data (e.g., 1xRTT and UMTS). Types of analysis include RF capacity, end-to-end performance, and provisioning. The data models for telnet, WWW, ftp, e-mail, FAX, and WAP services are considered.

Multi-Carrier Traffic Allocation, June '99 to Sept. '01

- Provided MCTA capacity improvements (compared to non-MCTA systems) that proved to be identical to the ones observed during the field-testing. Developed a method to estimate the MCTA capacity using the field data. This method was used in estimating MCTA capacity gains by RF engineering teams.

SmartRate and Related Vocoder Designs (e.g., SMV), June '99 to Sept. '01

- Provided estimates of SmartRate capacity improvements that were found to be close to the observed capacity gains in the field tests.

CDMA Based Fixed Wireless Access Systems, Sept. '97 to Dec. '98

- **Capacity Estimates**. Determined the system capacity for a variety of configurations using an IS-95 based simulator. These configurations include different rates such as 9.6 kbps and 13 kbps, different deployment scenarios such as 2-tier embedded sector and border sector, and different diversity techniques such as switch antenna diversity and phase sweeping transmit diversity. These capacity estimates were used for various project bids. The simulator utilizes propagation channel models extracted from the actual field measurements.
- **Handoff and Power Control Algorithms**. Analyzed existing handoff and power control mechanisms for fixed wireless systems and proposed new approaches.
- **Bridge between the Simulator and a Deployed System**. Developed a procedure to estimate the loading level for the simulator so that the capacity estimate from the simulator is close to the achieved capacity in real systems.
- **Switch Antenna Diversity Schemes**. Proposed three algorithms to exploit mobile switch antenna diversity. These schemes provide a low-cost solution that significantly enhances RF capacity.
- **Combined Overhead Power and Handoff Management**. Proposed a method of combined management of overhead channel power and handoff to improve capacity.

Educator

- Made presentations on topics such as data modeling, fixed wireless systems, and AI tools.
- Taught "Introduction to Wireless" class at Nortel.
- Prepared tutorials on the standards such as 1xRTT, 1xEV-DO, and UMTS.

VIRGINIA TECH *January '93 to August '97*

Research/Teaching Assistant, Mobile & Portable Radio Research Group (MPRG), Electrical Engineering

- Developed adaptive intelligent handoff algorithms to preserve and enhance the capacity and the Quality of Service of cellular systems.
- Helped *develop* and *teach* a new wireless communications course **(DSP Implementation of Communication Systems**) as part of an **NSF** sponsored curriculum innovations program. Implemented different subsystems of a communication system (e.g., a digital transmitter, a carrier recovery system, a code synchronizer, and a symbol timing recovery system) using the **Texas Instruments** TMS320C30 DSP development system.
- Refined the class material for undergraduate and graduate signal processing classes.
- Investigated different aspects involved in dual-mode adaptive reconfigurable receivers as part of a project sponsored by **Texas Instruments**.

PATENTS/DRAFTS (AUTHOR/CO-AUTHOR)

- Enhanced Power Control Algorithms for CDMA-Based Fixed Wireless Systems, Patent Number 6,587,442, Filed Date: October 28, 1999.
- Method and apparatus for managing a CDMA supplemental channel, Patent Number 6,862,268, Filed Date: December 29, 2000.
- Dynamic Power Partitioning Based Radio Resource Management Algorithm, Patent Disclosure No.: 11942RR, Filed Date: August 23, 2000.
- Switch Antenna Diversity Techniques at the Terminal to Enhance Capacity of CDMA Systems, Patent Disclosure No. RR2544, Filed Date: June 19, 1998.
- Adaptive Radio Configuration Assignment for a CDMA System, October 2003.
- Multi-carrier Load Balancing for Mixed Voice and Data Services, October 2003.
- Methodology for Hierarchical and Selective Overload Control on Forward and Reverse Links in a CDMA System, October 2003.
- A New Predictive Multi-user Scheduling Scheme for CDMA Systems, November 2003.
- A New Method for Solving ACK Compression Problem by Generating TCK ACKs based on RLP ACKs on the Reverse Link, October 2003.

ACTIVITIES

Member of **IEEE**. Reviewed research papers for the *IEEE Transactions on Vehicular Technology*, *IEE Electronics Letters* and the *IEEE Control Systems Magazine*.

EDUCATION

VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIVERSITY **Blacksburg, VA**
Ph.D., Wireless Communications, August 1997, Overall GPA: 3.8/4.0
Dissertation: Generic adaptive handoff algorithms using fuzzy logic and neural networks

M.S., Electrical Engineering, November 1994, Overall GPA: 3.8/4.0

GUJARAT UNIVERSITY **Ahmedabad, India**
B.S., Electrical Engineering, September 1992
Graduated among the top 2% of the class.

ATTACHMENT B

ECONOMIC ANALYSIS OF PUBLIC POLICY REGARDING MOBILE SPECTRUM HOLDINGS:

Reply Declaration of Mark A. Israel and Michael L. Katz

JANUARY 7, 2013

CONTENTS

I. INTRODUCTION 1

II. ALL SPECTRUM SUITABLE FOR MOBILE WIRELESS SERVICES SHOULD BE COUNTED EQUALLY IN A SINGLE SCREEN 4

A. PROFESSOR PEHA'S ANALYSIS REINFORCES OUR EARLIER CONCLUSION THAT A WEIGHTED SPECTRUM SCREEN WOULD BE ILLOGICAL AND FAIL TO PROVIDE ANY PUBLIC-INTEREST BENEFITS 6

1. Professor Peha's analysis demonstrates that the values of high- and low-frequency spectrum differ only in areas with no significant risk of foreclosure 8

(a) The data for spectrum shares and downstream-market shares demonstrate that foreclosure is not a concern in suburban and rural areas. 9

(b) The license prices per MHz-Pop paid at auctions support a finding that the use of spectrum aggregation to foreclose competition is very unlikely in rural areas. 16

2. Professor Peha's analysis of auction prices and associated network costs provides further evidence that value-based weights make no sense 18

B. PROFESSOR PEHA'S ANALYSIS CONFIRMS THAT A WEIGHTED SPECTRUM SCREEN WOULD BE DIFFICULT TO DESIGN AND IMPLEMENT 21

1. Frequency-based weights would have to vary by the nature of the license area. 22

2. Professor Peha's frequency-based weights would constantly be changing, thus creating uncertainty and giving rise to likely inequities 22

C. THE DIFFICULTIES WITH A SPECTRUM WEIGHTING SCHEME ARE NOT OVERCOME BY THE USE OF "MARKET VALUE" WEIGHTS 23

D. A SEPARATE SCREEN FOR SPECTRUM BELOW 1 GHZ ALSO MAKES NO ECONOMIC SENSE 25

III. COMMENTS CALLING FOR IMPOSITION OF ONE OR MORE SPECTRUM CAPS ARE FUNDAMENTALLY FLAWED 26

A. FREE PRESS'S PROPOSAL TO IMPOSE A SPECTRUM CAP COUPLED WITH A HERFINDAHL-HIRSCHMAN INDEX-BASED SCREEN LACKS ANY SOUND JUSTIFICATION 26

1. For all of the reasons explained in our Initial Declaration, a spectrum cap would harm competition and consumers.............................27

2. Free Press's proposed screen has no basis in antitrust policy and would generate many false positives..28

B. SPRINT'S PROPOSAL FOR A SEPARATE SPECTRUM CAP FOR HOLDINGS BELOW 1 GHZ LACKS ANY SOUND JUSTIFICATION..29

1. Data on spectrum holdings and market shares show little correlation between spectrum holdings below 1 GHz and marketplace outcomes...30

2. There are numerous examples of firms competing effectively using only spectrum above 1 GHz..32

C. T-MOBILE USA'S AND UNITED STATES CELLULAR CORPORATION'S PROPOSALS FOR A CAP ON AUCTION PURCHASES ARE UNWORKABLE AND AGAINST THE PUBLIC INTEREST...36

IV. CONCLUSION 39

I. INTRODUCTION

1. At the request of counsel for AT&T, we conducted an economic analysis that: (a) examined what spectrum-holding policy regime would best protect competition and promote consumer welfare, and (b) addressed several specific questions posed by the Federal Communications Commission (Commission) in its recent notice of proposed rulemaking.[1] Our broad conclusion was—and still is—that competition and consumers are best served by a reinvigorated commitment to use of a spectrum screen (set at a level equal to at least one-third of suitable spectrum, counting all suitable frequencies equally) as a true safe harbor.[2] As we explained in our *Initial Declaration*, the screen should be coupled with case-by-case review of instances in which spectrum holdings exceed the screen in local markets, with that review utilizing clear principles transparently applied.[3] In those situations where case-by-case review is undertaken, remedial action should be taken only when principled analysis demonstrates likely harm to competition in one or more local markets for mobile wireless services. Any remedies should be carefully targeted to the specific competitive harms triggered by the transaction in the market or markets in which those harms occur. As we further explained in our *Initial Declaration*, imposing a hard cap on spectrum aggregation would harm competition and consumers.[4]

---

1 *In the Matter of Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269, Notice of Proposed Rulemaking, rel. September 28, 2012 (hereinafter, *NPRM*).

2 Mark A. Israel and Michael L. Katz, Economic Analysis of Public Policy Regarding Mobile Spectrum Holdings, November 28, 2012 (hereinafter, *Israel and Katz Initial Declaration*), Attachment A to Comments of AT&T Inc., *In the Matter of Policies Regarding Mobile Spectrum Holdings,* WT Docket No. 12-269.

3 *Israel and Katz Initial Declaration,* ¶ 56.

4 *Id.*, § III.A.

2. We have now been asked by counsel for AT&T to assess economic arguments and policy proposals made in filings submitted in this proceeding contemporaneously with our *Initial Declaration*.[5] In those filings, several parties suggest approaches very different from the one that our analysis recommends. In particular, these parties advocate policies that would benefit some wireless carriers by constraining the ability of other wireless carriers to compete against them effectively.

3. We find that the parties advocating these alternative approaches fail to provide logically sound, fact-based analysis demonstrating that their proposed policies would promote competition and consumer welfare. As we explain below, their proposed policies would, in fact, harm competition and consumer welfare while threatening to reduce the U.S. Treasury's revenues from spectrum license auctions and distorting the reallocation of spectrum from broadcast television to mobile wireless services.

4. Turning to specific policy proposals, our findings regarding these submissions are the following:

- Several commenters, including Public Knowledge and Sprint, call for the use of a screen that assigns different weights to spectrum holdings of different frequencies. In our *Initial Declaration,* we explained why this approach is contrary to fundamental economic logic, for reasons including its lack of grounding in a coherent theory of foreclosure and its failure to recognize the fact that any economically relevant differences in spectrum characteristics will be reflected in equilibrium license prices. Comments by proponents

---

5 We have not attempted to identify and analyze every argument made. The fact that an argument may have been raised without our discussing it below does not indicate that we support that argument or believe that its conclusions are correct.

of frequency-based weights offer no sound arguments to reverse our initial conclusions. Indeed, comments submitted on behalf of Public Knowledge by Professor Jon Peha (a proponent of differential weighting) further bolster our initial findings by demonstrating how complex, impractical, and misguided it would be to implement spectrum screens that varied by frequency or were weighted by some measure of the financial value of the spectrum at issue.

- Several commenters, including T-Mobile USA, the Competitive Carriers Association, and the Computer and Communication Industry Association, advocate a separate screen for spectrum below 1 GHz. As we explain below (building on ideas explained in our *Initial Declaration*), imposing a separate "low-frequency screen" would distort competition and harm consumers. Here, too, Professor Peha's analysis bolsters our conclusion, in this instance by demonstrating that the 1 GHz cutoff is not a meaningful distinction in those areas where foreclosure concerns might conceivably arise.

- Free Press proposes that the Commission impose a hard 35-percent cap and couple it with a concentration analysis. Although Free Press asserts that its proposal has a sound basis in antitrust policy, this assertion is false. If implemented, Free Press's proposal would harm competition and consumers, which is an outcome directly counter to the central objectives of antitrust policy. Free Press's proposed policy would have these adverse effects by making expansion more costly for those carriers that are the most successful at offering services that consumers value highly. The bright-line limits on spectrum holdings proposed by NTCH, Inc., and the Rural Telecommunications Group, Inc., would harm competition and consumers through the same mechanism.

- Sprint proposes a hard cap that would apply specifically to spectrum below 1 GHz. Like a frequency-weighted spectrum screen, this policy proposal is based on the false premise that spectrum below 1 GHz is of particular importance in a foreclosure analysis. At core, a cap on spectrum holdings below 1 GHz is simply an arbitrary cap on a subset of the available inputs that fails to consider the existence of other, substitute inputs and, thus, makes no sense as a matter of economics. Like other hard-cap proposals, Sprint's proposal would harm consumers by limiting and distorting competition.
- Lastly, certain commenters, including T-Mobile USA and United States Cellular Corporation, call for a spectrum cap that would apply only to initial license auctions, with a spectrum screen and case-by-case analysis used for secondary-market transactions. As we explain below, such a distinction by type of transaction is meaningless at best and is very likely to be harmful. If implemented, such a proposal would: risk harm to competition and consumers; threaten to reduce auction revenues; and, in the case of the 600 MHz broadcast television spectrum auction, threaten to reduce the amount of spectrum allocated to mobile wireless services.

5. The remainder of this declaration explains these findings in greater depth and provides details of the facts and analysis that underlie them.

II. ALL SPECTRUM SUITABLE FOR MOBILE WIRELESS SERVICES SHOULD BE COUNTED EQUALLY IN A SINGLE SCREEN

6. Public Knowledge and Sprint call for the consideration or adoption of a screen that assigns different weights to spectrum holdings of different frequencies.[6] T-Mobile USA, the

6 Updating the Spectrum Screen, Comments for Public Knowledge, *In the Matter of Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269, November 28, 2012 (hereinafter,

Competitive Carriers Association, and the Computer and Communication Industry Association, advocate a separate screen for spectrum below 1 GHz.[7] In our *Initial Declaration*, we explained that frequency-based weights and financial-value-based weights had no sound foundation in either economics or engineering.[8] The same holds true for having a separate screen for spectrum below 1 GHz.

7. Not surprisingly, comments submitted by proponents of weighting schemes and separate screens fail to offer any valid arguments to counter the conclusions in our *Initial Declaration*. Indeed, comments filed by Professor Jon Peha—intended to express support for implementation of a spectrum screen with differential weighting—actually support the conclusion that the Commission should *not* implement policies that apply different weights (or separate screens) to

---

Peha Comments) at 2 ("…the FCC's spectrum screen must treat spectrum assignments differently depending on their frequency band."); Comments of Sprint Nextel Corporation, *In the Matter of Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269, November 28, 2012 (hereinafter *Sprint Nextel Comments*) at 9 ("The Commission should address the risk of harm to competition and consumers by (1) modifying its existing spectrum screen so that the different frequency bands counted under the screen are weighted according to their relative values in the marketplace, and (2) adopting a spectrum cap for spectrum under 1 GHz.").

[7] Comments of T-Mobile USA, Inc., *In the Matter of Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269, November 28, 2012 (hereinafter, *T-Mobile Comments*) at 17 ("In transactions, the Commission would take an analogous approach but with a spectrum screen. In transactions involving the acquisition of spectrum below 1 GHz, in addition to a review of the carrier's total spectrum holdings in a market, the Commission would analyze the carrier's spectrum below 1 GHz in that market using the one-third spectrum screen."); Comments of the Computer & Communication Industry Association, *In the Matter of Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269, November 28, 2012 (hereinafter, *CCIA Comments*) at 10 ("The Commission can remedy the failures of the current screen and limit the opportunities for gamesmanship and unintended consequences a single screen creates by adopting a second spectrum-screen for the high-value spectrum below 1 GHz.").

[8] *Israel and Katz Initial Declaration*, §§ IV.D.1 and IV.D.2.

spectrum in different frequency bands suitable for mobile wireless service, whether based on claims regarding propagation characteristics or some measure of the spectrum's financial value.[9]

A. PROFESSOR PEHA'S ANALYSIS REINFORCES OUR EARLIER CONCLUSION THAT A WEIGHTED SPECTRUM SCREEN WOULD BE ILLOGICAL AND FAIL TO PROVIDE ANY PUBLIC-INTEREST BENEFITS

8. In his statement, Professor Peha advocates use of a weighted spectrum screen, with weights based on the costs of building out a wireless network using spectrum in a given frequency band. As we explained in our *Initial Declaration*, the relevant public-interest question that a screen should help to answer is whether there is a meaningful risk that a wireless carrier may accrue sufficient spectrum to have the ability and incentive to foreclose competition in one or more downstream mobile wireless markets.[10] As such, to be valuable, a spectrum screen must be able to distinguish transactions that pose significant risks of foreclosure from those that do not. A firm would have the ability (although not necessarily the incentive) to engage in foreclosure only if it could raise the costs of actual and potential rivals sufficiently to lead to significantly higher prices and/or lower quality and, thus, significantly lower consumer welfare.

9. Once one recognizes that it is critical to ground any screen in an assessment of the risk of foreclosure—a step Professor Peha does not take—it becomes clear that Professor Peha's analysis actually supports our original conclusion that a weighted spectrum screen would be inappropriate. It does so for two main reasons:

9 In their declaration submitted contemporaneously with ours, Professor Reed and Dr. Tripathi identify technical flaws in Professor Peha's analysis. These flaws—although important to recognize—change neither the fact that Professor Peha's work is substantially more thoughtful than the highly superficial comments submitted by most parties nor the fact that his analysis, when properly understood, generally supports our positions. (Jeffrey H. Reed and Nishith D. Tripathi, "The Value of Spectrum, A Response to Professor Jon M. Peha's Paper," January 7, 2012 (hereinafter, *Reed-Tripathi Response*).

10 *Israel and Katz Initial Declaration*, § II.B.4.

- First, Professor Peha argues that high- and low-frequency spectrum holdings are equally valuable in the only markets in which there is even a conceivable risk of foreclosure based on spectrum aggregation levels near those seen in practice. In those markets for which Professor Peha argues that there is an important distinction between high- and low-frequency spectrum holdings, spectrum is not a sufficiently scarce resource to serve as a basis for foreclosure without a carrier's obtaining licenses to a substantial majority of the spectrum in a local market.

- Second, although Professor Peha correctly points out that spectrum holdings can affect competition by affecting the cost of expanding capacity, he fails properly to account for the fact that the cost of capacity includes *both* the cost of acquiring spectrum and the cost of the facilities build-out associated with that spectrum.[11] Over the range of frequencies he examines in his comments, Professor Peha finds that licenses for higher-frequency spectrum generally sell for less than those for lower-frequency spectrum, and they do so by amounts that offset the increase in facilities build-out costs that he estimates are associated with higher frequencies. Hence, his analysis supports the conclusion that there is no meaningful distinction between high- and low-frequency spectrum from the perspective of a foreclosure analysis.

We explore each of these points in the remainder of this section.

---

11 *Peha Comments* at 4.

1. Professor Peha's analysis demonstrates that the values of high- and low-frequency spectrum differ only in areas with no significant risk of foreclosure

10. Professor Peha's analysis indicates that a scheme with differential weighting by frequency band cannot be justified in areas with high demand for mobile wireless services, which he labels "dense urban" areas. As Professor Peha discusses, where demand is high, cell sizes must be relatively small to maintain sufficient capacity for mobile wireless service. In those circumstances, both high- and low-frequency spectrum can provide complete coverage for an entire cell. This fact leads Professor Peha to conclude that "the value of a MHz-POP of spectrum … should be roughly the same in all frequency bands …" in dense urban areas.[12] By the own logic of proponents of weighted screens, this conclusion undermines the claim that greater weight should be given to holdings of lower-frequency spectrum in a screen.[13]

11. In contrast with dense urban areas, Professor Peha's analysis finds that spectrum values per MHz-POP vary by frequency band in suburban and rural areas. However, as we will now show, the potential competitive problems that a spectrum screen should be intended to identify are very unlikely to arise in suburban and rural areas at spectrum concentration levels anywhere near those seen in practice.

---

12 *Peha Comments* at 9.

13 Moreover, Professor Reed and Dr. Tripathi show that, in dense markets, low-frequency spectrum may actually be inferior to high-frequency spectrum because use of low-frequency spectrum suffers from greater incidence of interference. (*Reed-Tripathi Response* at 9 and 10.) This fact further undermines calls for giving greater weight to low-frequency holdings.

(a) The data for spectrum shares and downstream-market shares demonstrate that foreclosure is not a concern in suburban and rural areas.

12. For the reasons we explained in our *Initial Declaration*, spectrum aggregation policy should focus squarely on the potential for anticompetitive foreclosure in downstream wireless markets, which is where consumer welfare is determined.[14] In order to demonstrate a credible threat of foreclosure, one would need, as a starting point, to establish the following necessary (but not sufficient) condition: *That there exist a tight linkage between concentration of spectrum holdings and market concentration in the downstream mobile wireless market*.[15] Absent demonstration of such a linkage, the entire enterprise of regulating spectrum aggregation lacks a sound rationale. As we will now demonstrate, this necessary condition is not satisfied in suburban and rural markets.

13. In our data analysis, we use the universe of all CMAs other than the 50 largest (as measured by population) as our sample. We are being conservative by looking at all CMAs outside of the top 50 (rather than say all CMAs outside of the top 100 or top 200) because including more populous, denser CMAs (*e.g.*, Honolulu, HI, and Dayton, OH) makes it more likely that one will find a positive relationship between spectrum holdings and downstream-market shares because more populous, denser CMAs are the ones in which spectrum scarcity is likely to be greater.

---

14 *Israel and Katz Initial Declaration*, § II.

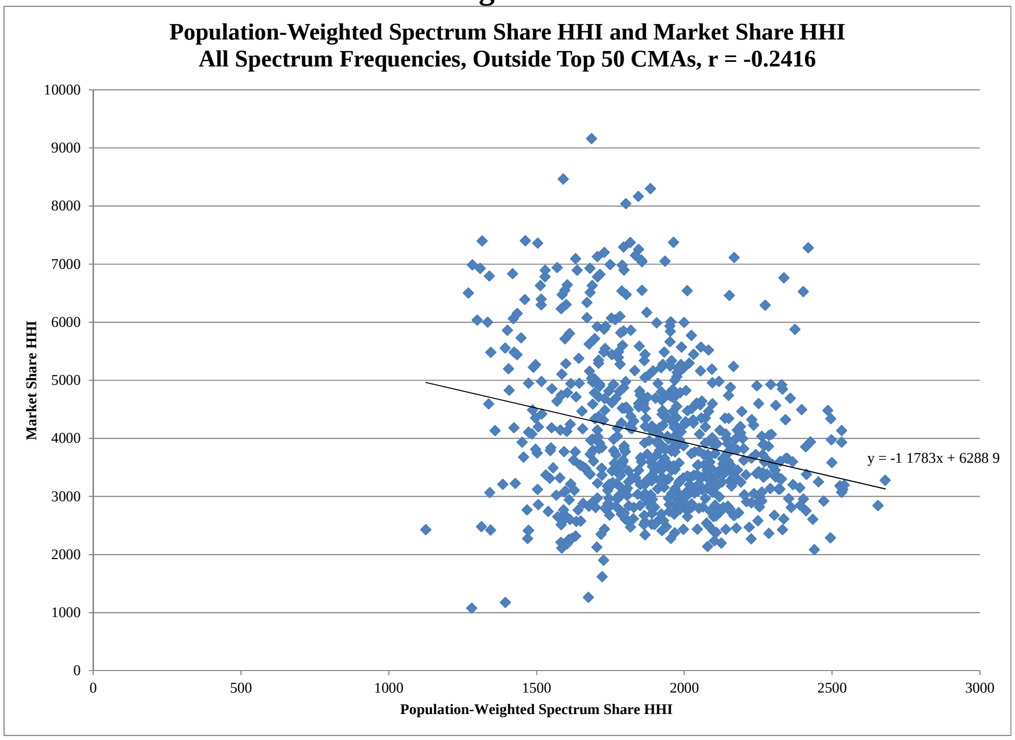
15 It is important to recognize that, although a necessary condition, establishing the existence of such a linkage is *not* a sufficient condition for the existence of foreclosure concerns. There are many reasons for this conclusion, including the facts that: (a) the causality underlying such a linkage might run in the reverse direction, and (b) greater market concentration is not necessarily bad for consumer welfare (*e.g.*, if concentration has increased because one company has done an exceptionally good job at satisfying consumer desires).

14. An examination of data for spectrum-holding concentration and downstream-market concentration reveals *no* evidence of a strong, positive relationship between spectrum-holdings concentration and downstream-market concentration outside of the top 50 CMAs. To analyze the data, we calculated Herfindahl-Hirschman Indices (HHIs) based on: (a) shares of spectrum license holdings by CMA, and (b) estimated mobile wireless market shares by CMA.[16, 17] These HHIs are plotted in Figure 1 below. Each point on the chart represents the HHI based on spectrum shares and the HHI based on estimated downstream-market shares in a particular CMA.

16 Calculations based on *AT&T Market Share Estimates* and the Commission's *Spectrum Dashboard*. For this analysis, we use population-weighted spectrum holdings only (excluding leases) to avoid double counting of leases and held licenses. The *AT&T Market Share Estimates* do not separately identify the shares of all carriers in all CMAs, instead leaving some in an "other" category. The HHI figures we present throughout this declaration compute estimated-market-share HHI by treating any such unidentified firms as part of a perfectly competitive fringe that contributes nothing to the market share HHI (effectively treating all of their shares as zero, as though an infinite number of firms make up the other category). We have also run the analyses for the polar opposite case in which any share reported in the "other" category in each CMA is treated as belonging to a single carrier for purposes of calculating the estimated-market-share HHI. This alternative means of calculating the HHI has no effect on any of our substantive conclusions. In addition, we have run the analyses dropping all CMAs in which the "other" carriers make up more than 5 percent of the total estimated market share (treating the other carriers in the included CMAs as part of a perfectly competitive fringe), again with no change to our substantive conclusions.

17 Our examination of Commission license data has identified errors in those data. For example, the Commission's *Spectrum Dashboard* shows Cellular block A spectrum as being unassigned in many counties in Northern Virginia. This is inaccurate; AT&T has the Cellular A license throughout CMA 8, which includes Northern Virginia.

Figure 1



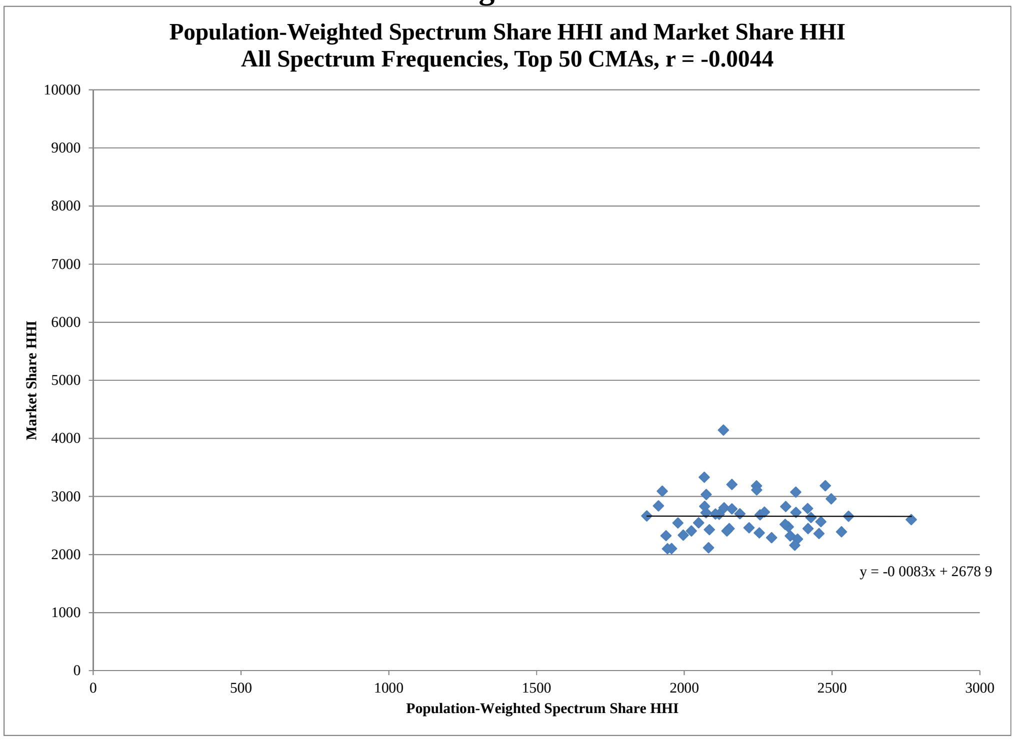
15. Visual examination of Figure 1 certainly does not support the conclusion that spectrum concentration drives downstream-market concentration in suburban and rural markets. The lack of such a relationship can also be seen via the “correlation coefficient” for the spectrum-share HHI and the estimated-market-share HHI in these CMAs. The correlation coefficient is a standard measure of the strength of the relationship between two variables, with a coefficient of 1 indicating a perfect positive relationship (as one variable goes up the other goes up in lockstep), a coefficient of -1 indication a perfect *inverse* relationship (as one variable goes up, the other goes down in lockstep), and 0 indicating no relationship. For CMAs other than the top 50, the correlation coefficient for spectrum HHI and market HHI is –0.2416. In words, spectrum concentration and downstream-market concentration are *inversely* related in these data. The natural conclusion from this fact—which is illustrated by the lack of any clearly visible pattern in Figure 1—is that there is no tight, positive relationship between spectrum concentration and

market concentration in these CMAs and, thus, no basis for foreclosure concerns at spectrum concentration levels near those seen in practice.[18]

16. Further support for this conclusion is provided by examination of the relationship between spectrum concentration and downstream-market concentration in the top 50 CMAs, which are the areas in which one would expect spectrum availability to matter the most. Even here, one finds effectively no relationship between spectrum and market concentration. Figure 2 plots the data and reports that the correlation coefficient between HHI based on spectrum share and HHI based on estimated market share is slightly negative, at -0.0044. Combined with our analysis of CMAs other than the 50 largest, this finding supports the overall conclusion that there is no strong, positive relationship between spectrum concentration and market concentration observed in the data.

[18] Below, we discuss fundamental flaws in Free Press's proposal to utilize a spectrum screen based on the spectrum HHI. The analysis in the present paragraph also illustrates a core flaw in the Free Press proposal: To the extent market concentration matters, it is concentration in downstream mobile wireless markets, and the data examined in the present section clearly indicate that spectrum HHI is not a good predictor of such downstream concentration.

Figure 2



17. Examination of data at the firm—rather than market—level also supports the conclusion that foreclosure is unlikely to be a concern in CMAs outside of the top 50. Applied to such data, the necessary condition for the existence of foreclosure concerns can be stated as: *That there exist a tight linkage between a wireless carrier's share of available spectrum and its market share in downstream mobile wireless service markets.*[19]

18. Figure 3 below plots estimated market shares and spectrum-holding shares for mobile wireless service providers in the CMAs outside the top 50.[20] Each point on the chart represents the spectrum-holding share and estimated market share for a particular wireless carrier in a

---

19 Again, such a linkage is a necessary but not sufficient condition for foreclosure concerns: Any observed linkage could simply reflect the fact that firms that are more successful need more spectrum to serve their traffic.

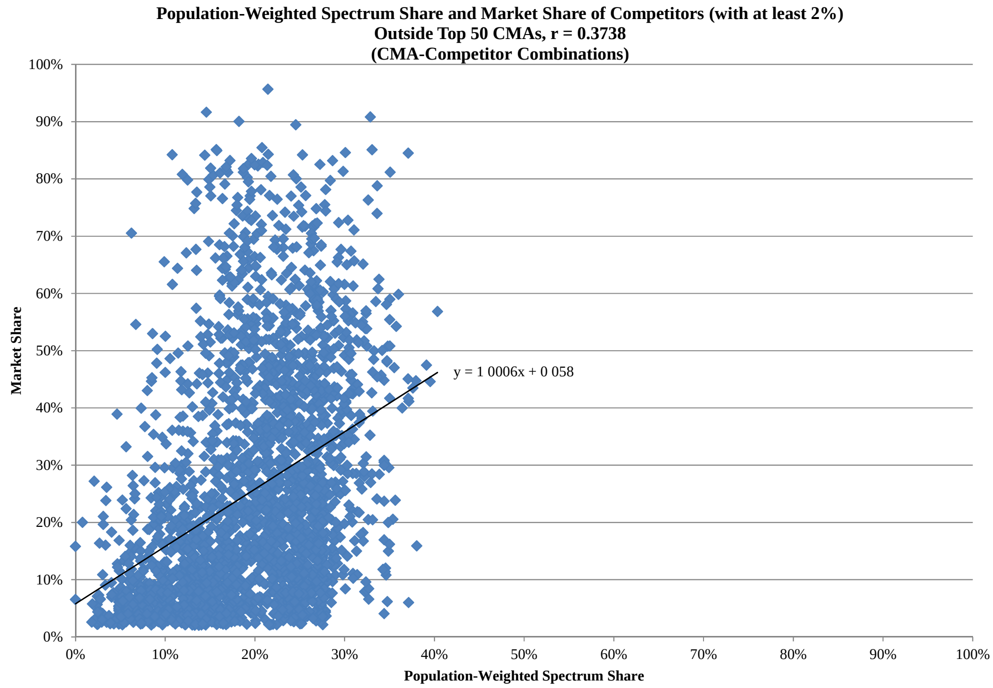
20 Calculations based on *AT&T Market Share Estimates* and *Spectrum Dashboard*. For this analysis, we use population-weighted spectrum holdings only (excluding leases) to avoid double counting of leases and held licenses.

particular CMA where that carrier has at least a two-percent estimated market share.[21] A look at the data clearly reveals that carriers are successfully competing with very different spectrum shares: A high spectrum share is no guarantee of a high market share, and a low spectrum share need not be an obstacle to attaining a high market share. In addition to being visible in the figure, this fact is demonstrated by the low correlation of spectrum share with estimated market share; it is only 0.3738. That the correlation is positive is to be expected because, all else equal, those service providers that are more successful at attracting consumers have greater demands for spectrum usage rights. The low value of this coefficient means that the vast majority of the variation in estimated market shares in these CMAs is explained by factors other than a carrier's spectrum share in the area. In other words, a wireless carrier's obtaining additional spectrum neither guarantees it market success nor precludes rival carriers from being successful.

---

[21] In our *Initial Declaration*, we plotted the estimated market shares and spectrum-holding shares for mobile wireless service providers in the 50 largest CMAs. There, we included all carriers with share greater than five percent in the CMA. In the present declaration, we changed the cutoff to two percent to be consistent with standard Commission practice of counting a carrier as a competitor in a CMA if it has at least two percent of connections in the CMA. (*In the Matter of Implementation of Section 6002(b) of the Omnibus Budget Reconciliation Act of 1993 Annual Report and Analysis of Competitive Market Conditions With Respect to Mobile Wireless, Including Commercial Mobile Services*, WT Docket No. 10-133, Fifteenth Report, rel. June 27, 2011 (hereinafter, *Fifteenth CMRS Competition Report)*, ¶ 47.) In both our *Initial Declaration* and the present declaration, the estimated- market-share figures also exclude any carriers not separately identified in the *AT&T Market Share Estimates.*

Figure 3



19. Despite the data, a proponent of the spectrum screen might argue that a strong, positive relationship would emerge if one were to consider much higher levels of concentration of spectrum holdings than are observed in practice. Our response to this point is twofold. First, although the emergence of such a relationship is a theoretical possibility, the fact remains that the available data do not suggest such a finding. Second, even if such a relationship existed at very high levels of spectrum concentration, it would not alter the conclusion that, over the range of concentration levels currently observed, there is no evidence in support of imposing a more stringent screen or any form of spectrum cap in rural and suburban areas.[22]

---

22 In our *Initial Declaration*, we demonstrated that it would also be unsound to impose a more stringent screen or any form of spectrum cap in dense, urban areas. (*Israel and Katz Initial Declaration*, §§ III.A and III.D.)

(b) The license prices per MHz-Pop paid at auctions support a finding that the use of spectrum aggregation to foreclose competition is very unlikely in rural areas.

20. Additional evidence that, in rural areas, spectrum is not the type of scarce resource likely to give rise to foreclosure concerns comes from the outcomes of spectrum auctions. In particular, the price per MHz-POP paid at auction for spectrum is much lower in rural areas than in urban areas. Figure 4-A below shows that, the winning bid in the AWS-1 auction (A-block) was substantially lower for licenses outside the most densely populated CMAs than in those CMAs. Figure 4-B shows the same relationship for the winning bids in the Lower 700 auction. The lower price per MHz-POP in less-densely populated areas indicates that spectrum is considerably less scarce in those areas.

Figure 4-A

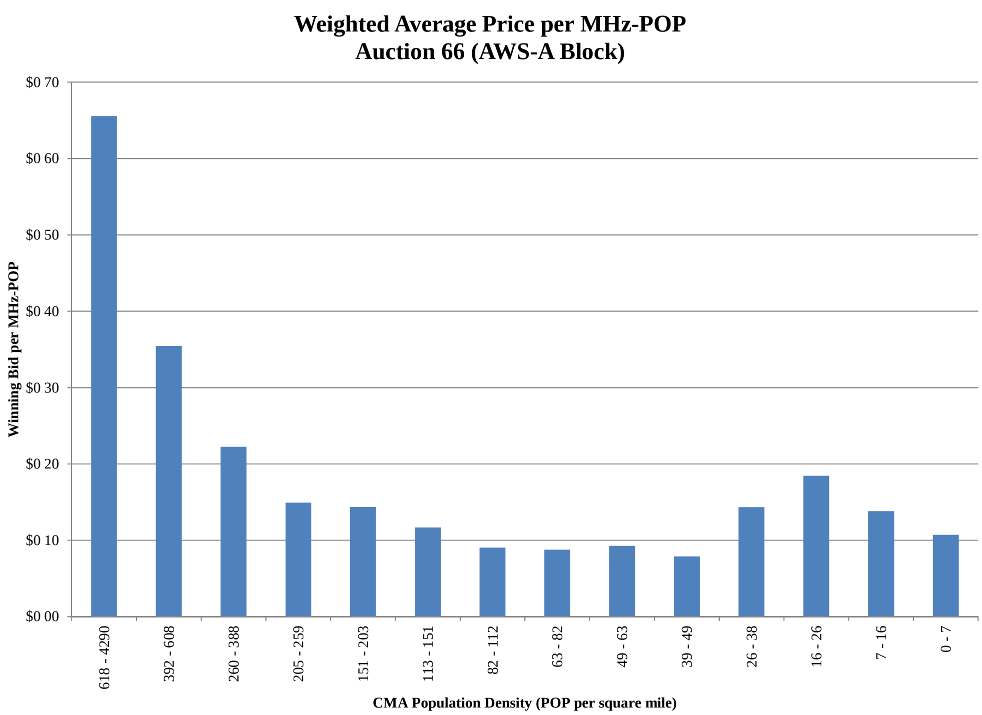
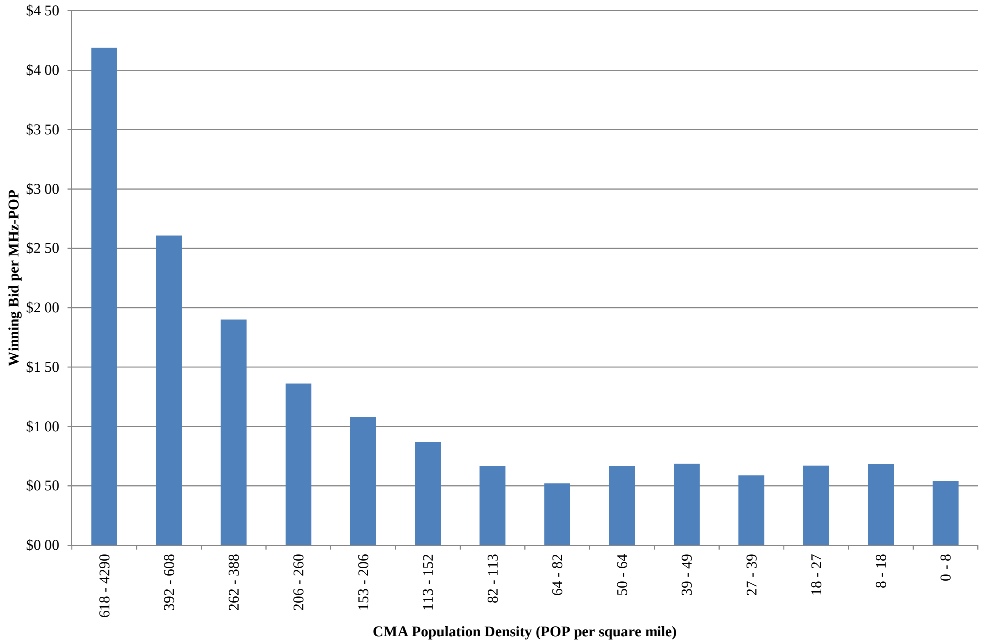


Figure 4-B

Weighted Average Price per MHz-POP
Auction 73 (Lower 700MHz B Block)



21. One might attempt to dismiss the analysis presented thus far based on the assertion that, over time, wireless traffic will increase in some areas outside the top urban CMAs, thus potentially making spectrum scarcity a bigger concern in the areas in which Professor Peha argues that spectrum is differentially valuable. However, Professor Peha's analysis also shows why this possibility, even if true, does not provide a justification for differential spectrum weighting based on current differences in the value of high- and low-frequency spectrum in such areas. In particular, the defining characteristic of Professor Peha's "dense urban" market scenario is that, to meet capacity needs, cells must be small enough that they can be served fully by high-frequency spectrum. As usage increases in any given market (whether "rural" or "suburban"), that market will move toward meeting this condition. That is, the same forces that make spectrum scarcity a concern in any given market also cause that market to move toward

Professor Peha's dense urban case, where low- and high-frequency spectrum holdings are equally valuable.

2. Professor Peha's analysis of auction prices and associated network costs provides further evidence that value-based weights make no sense

22. In an auction or other spectrum transaction, economics predicts that the selling price of spectrum will depend on the value of that spectrum, meaning—per Professor Peha's argument—the extent to which it reduces the cost of expanding capacity. Hence, to the extent that high-frequency spectrum necessitates greater additional cost to achieve a certain degree of capacity expansion, all else equal, the price of that spectrum is expected to be lower, thus offsetting the higher cost of expansion. Put simply, even if spectrum truly differs in quality, a potential entrant or expanding incumbent can either: (a) buy expensive, "good" spectrum and then pay less in additional investment to reach a given capacity level, or (b) buy less-expensive, "bad" spectrum and then pay more in additional investment. As such, there is no reason to believe that a firm that has to rely on "bad" spectrum will have to pay more in total to enter or expand and, thus, there is no implication that such a firm will be foreclosed.

23. A simple analogy helps to make the point. Imagine purchasing a backyard swing set in one of two ways, either: (a) delivered and assembled by the manufacturer, or (b) available for pick up at a retail store with substantial assembly required. It is certainly true that a family buying the version requiring assembly must incur post-purchase costs to make the swing set usable. But it is also true that the upfront cost of the swing set will surely reflect these assembly costs. As a result, an argument that, if certain families were "forced" to buy the swing set requiring assembly, they would be "foreclosed" from having a swing set due to the assembly

costs would obviously be incorrect. Indeed, many families would rather purchase the unassembled swing set because of the lower initial outlay.

24. Although the argument that families would be foreclosed from swing sets clearly is illogical, this is precisely the structure of the argument that asserts that carriers using high-frequency spectrum may be foreclosed due to high costs associated with building required network infrastructure, without recognizing that the spectrum itself will be cheaper due to these higher build-out costs. Of course it is not surprising that some carriers would push for policies that would effectively lower the price of the low-frequency spectrum (by limiting participation of carriers such as AT&T and Verizon in auctions for that spectrum)—everyone would prefer the assembled swing-set at the unassembled price—but such policies distort competition and protect certain competitors over others and, thus, harm consumers.

25. Of course, one might argue that markets do not work perfectly and, thus, that license prices do not reflect build-out costs in practice.[23] But Professor Peha provides evidence to the contrary. In particular, Figure 5 of his comments shows that auction prices for spectrum track closely to Professor Peha's estimate of the value of that spectrum based upon differences in infrastructure-deployment costs. This is exactly the pattern one would look for to confirm that spectrum-rights markets work efficiently and that lower-value spectrum (which requires greater additional investment to achieve a particular level of capacity) sells for a lower price that reflects (and offsets) this greater build-out cost. In any case, an argument that markets do not work perfectly provides no indication of whether they over- or under-compensate for any differences

---

23 Of course, to the extent that market values did not reflect the supposed "superiority" of low-frequency spectrum, there clearly would be no basis for adopting a weighted screen based on relative market values.

in spectrum quality and, thus, no basis to weight "high-quality" spectrum more or less than "low-quality" spectrum.

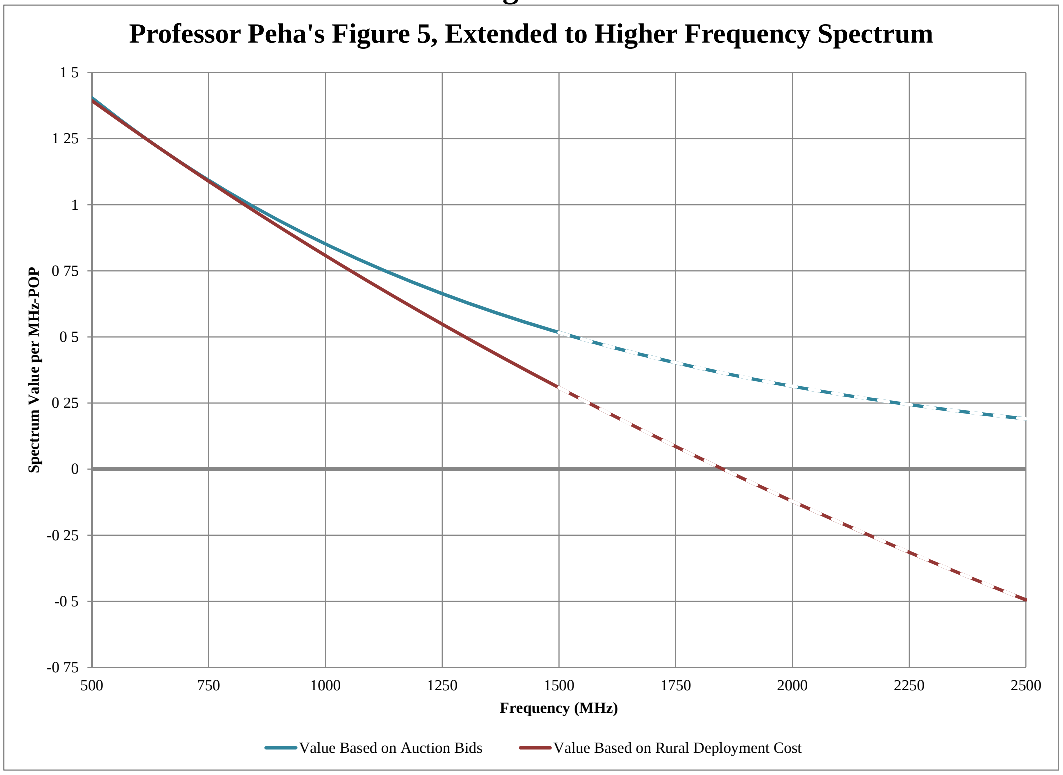
26. One might also contend that Professor Peha's auction value and infrastructure cost value curves begin to diverge at higher frequencies, and that this implies that infrastructure cost differences are not fully reflected in spectrum prices.[24] Upon closer examination, however, this divergence appears to reflect a breakdown in Professor Peha's infrastructure cost valuation algorithm when applied to higher frequencies: His algorithm predicts *negative* values for all of the high-frequency spectrum bands that are used by U.S. mobile wireless networks (*e.g.,* AWS, PCS, BRS/EBS). Below, we have reproduced Professor Peha's Figure 5 and have extended the calculations to cover higher-frequency spectrum bands. The value of spectrum per MHz-POP based on Professor Peha's projections of rural deployment costs is negative for frequencies higher than 1850 MHz. These negative values are implausible and are contradicted by recent market transactions (*e.g.,* Sprint paid billions of dollars to acquire the rest of Clearwire, and Verizon paid billions of dollars to acquire SpectrumCo.'s AWS spectrum). Professor Peha himself apparently recognizes that his estimates are invalid at higher frequencies, and he limits the scope of his comments to frequencies below 1500 MHz.[25]

---

24 It should also be recognized that the per-MHz, per-POP price of a spectrum license reflects a wide variety of factors (*e.g.*, the geographic scope of the license; the presence of incumbent users; and public-policy restrictions placed on the use of the spectrum), so that even if these prices fully reflect build-out costs, one might not observe perfect negative correlation in the data.

25 *Peha Comments* at 11.

Figure 5



B. PROFESSOR PEHA'S ANALYSIS CONFIRMS THAT A WEIGHTED SPECTRUM SCREEN WOULD BE DIFFICULT TO DESIGN AND IMPLEMENT

27. In our *Initial Declaration,* we explained why, even if there were a theoretically sound basis for a differential weighting scheme (and none has been presented), it would be very difficult to implement such a scheme in practice. Professor Peha's comments confirm our conclusion. Despite advocating differential weighting, Professor Peha is unable to propose any specific weighting scheme. Instead, he is able to say only that developing the appropriate weighting scheme is "not easy" and "beyond the scope of this filing."[26]

---

26 *Peha Comments* at 15.

1. Frequency-based weights would have to vary by the nature of the license area.

28. Given the inherent complexities in trying to determine the relative cost of network deployment as a function of frequency, Professor Peha only conducted a "simplified" analysis that purported to measure a subset of the relevant values. Even with regard to his simplified analysis, Professor Peha was unable to propose any specific weights. Professor Peha offers no workable definition of "dense urban," "rural," and "suburban" markets for his purposes.[27] The status of various areas could be in constant flux due to changes in consumer tastes, the introduction of new access devices, population growth, and other factors affecting the density and intensity of use in local markets. Because the rural and urban designations could favor some service providers over others, it can reasonably be expected that the classifications would be subject to intense lobbying and rent-seeking activities.

2. Professor Peha's frequency-based weights would constantly be changing, thus creating uncertainty and giving rise to likely inequities

29. In Professor Peha's discussion of a spectrum screen, he explains why the value of any particular spectrum license in terms of its ability to reduce a firm's network build-out costs is extremely complex and rapidly changing:[28]

> The actual value of a spectrum band in facilitating low-cost infrastructure is complex. It depends on frequency and bandwidth. It depends on how the band is fragmented in frequency and geography. It depends on what equipment is available in the band, which depends in turn on the extent to which regulators around the world have allocated the band for the same purpose, and for how long it has been used by CMRSs. It depends on the technical and business strategy of

[27] As noted above, Professor Peha also did not analyze many of the high-frequency bands actually used in the United States for LTE. Thus, even on its own terms, Professor Peha's analysis does not apply to many of the relevant spectrum bands.

[28] *Peha Comments* at 5 and 6.

> every carrier in the market. Not only are there too many factors to consider explicitly, but some of them can change rapidly.

The complex and rapidly changing assessment of value would lead to the need for frequent changes in the screen's weighting scheme, but the appropriate changes would be difficult to determine. This inherent difficulty would be exploited—and made worse—by the fact that there would be an obvious incentive for firms to attempt to influence the weights to benefit themselves rather than competition and consumers.[29] The continuing changes would also give rise to issues regarding the grandfathering of license holders, so that a holder would not find itself suddenly over the threshold because of changes in the weighting scheme.

C. THE DIFFICULTIES WITH A SPECTRUM WEIGHTING SCHEME ARE NOT OVERCOME BY THE USE OF "MARKET VALUE" WEIGHTS

30. The difficulties in implementing a spectrum weighting scheme are not overcome by using "market value" weights, as some commenters propose. Market-value weighting suffers from the same fundamental economic flaw as the engineering-driven weighting scheme advocated by Professor Peha: It fails to recognize that the cost of deploying mobile networks includes the cost of the spectrum itself. Put simply, if the market price of certain spectrum bands correctly reflects the fact that those bands will require higher subsequent investment costs than other spectrum bands—so that the price of those spectrum bands is lower than the price of spectrum bands requiring less subsequent investment—then the lower spectrum costs will offset the higher

29 The Commission would surely do its best to prevent the weighting scheme from being used in this way, but the Commission necessarily is in a position of inferior information relative to wireless carriers concerning their build-out plans, spectrum acquisitions they are considering, and other factors. Given such asymmetric information, there is substantial risk that private parties would undertake efforts toward (and potentially succeed in) distorting the implementation of any weighting scheme in their favor.

investment costs; the market has already corrected for the different spectrum characteristics, and no differential weighting is required.

31. In addition to the fatal logical flaw inherent in value weighting, there are—as Professor Peha persuasively explains—substantial practical and conceptual difficulties in using historical data to determine the appropriate market value of spectrum to apply in computing the weights:[30]

> Some have proposed using the winning bids in past auctions to determine the value of spectrum, or valuations that are simple multiples of winning bids. Winning bids provide useful information that should be considered, but they should not be accepted at face value. The problem is that the value bidders were willing to pay at the time of the auction may be quite different from the value today. Bids do depend on the intrinsic value of the spectrum being auctioned, but they depend on many other things as well. These include the level of pent-up demand for spectrum at the time of the auction, the number of carriers in a position to bid at the time of the auction, the interest rates at the time of the auction, the general state of the economy and therefore cellular revenues at the time of the auction, the regulations imposed on the winner which can vary from band to band, the extent to which the band has already been cleared and the cost of clearing it, the extent to which that spectrum band is available internationally which can also change over time, how adjacent spectrum bands are being used at the time of the auction, and more. Basing valuations only on auction bids, which at best are a snapshot of value from a previous era, could therefore introduce significant distortions.
>
> An alternative is to use spectrum values as determined through a secondary market after the auctions. These trades and leases may also produce information that the FCC should consider. The problem here is that the trades and leases are relatively infrequent and the financial details are sufficiently opaque that this also may produce an incomplete and perhaps distorted picture. Moreover, because of these (current) limitations of the spectrum market, overreliance on whatever data does exist may allow carriers to game the system. For example, a carrier may be able to make its holdings at a given frequency to appear less valuable by leasing a small amount of spectrum at that frequency at a price that is well below its market value. Similarly, a carrier may be able to make the holdings of a competitor appear more valuable by paying an inflated price for a small amount of spectrum at the same frequency.

---

30 *Peha Comments* at 12 and 13.

D. A SEPARATE SCREEN FOR SPECTRUM BELOW 1 GHZ ALSO MAKES NO ECONOMIC SENSE

32. The proposals to adopt a separate spectrum screen for holdings below 1 GHz are effectively more extreme versions of the proposed weighted screens. Such a screen would effectively treat all spectrum holdings above 1 GHz as *irrelevant* to whether foreclosure can occur. Absent a demonstration that large spectrum holdings below 1 GHz can, on their own, lead to foreclosure (or are somehow of particular importance), such a band-specific screen would be anti-competitive. This follows because such a screen would at least delay the consummation and increase the cost of transactions that violate this screen and would also raise the risk that such transactions ultimately would be blocked, potentially preventing firms from pursuing them in the first place even though the transactions would present no threat of actual foreclosure.

33. Once again, Professor Peha's analysis bolsters our conclusions. As noted above, a central finding of Professor Peha's analysis is that in "dense urban" areas, "the value of a MHz-POP of spectrum … should be roughly the same in all frequency bands …."[31] This important finding implies that applying a separate screen for spectrum under 1 GHz would make no sense in local markets for major metropolitan areas, because the urban areas, where demand for wireless services is most intense and is growing rapidly, are the areas in which the possibility of foreclosure is of concern.

34. This finding is reinforced by the evidence that we examine in Section III.B below, where we assess the arguments for a hard cap that applies to holdings of spectrum licenses below 1 GHz. Specifically, we show that firms—including new entrants—can succeed without holding licenses to spectrum below 1 GHz.

---

31 *Peha Comments* at 9.

III. COMMENTS CALLING FOR IMPOSITION OF ONE OR MORE SPECTRUM CAPS ARE FUNDAMENTALLY FLAWED

35. In our *Initial Declaration,* we explained why the return to a hard spectrum cap would be likely to harm competition and consumers. As we explained:[32]

> *Hard spectrum caps restrain those firms most successful at offering services that consumers find valuable and hinder competition, thus reducing consumer welfare, whereas case-by-case analysis, coupled with safe harbors and clear rules of the road regarding the factors considered in such analysis, protects against credible threats of market foreclosure while preserving incentives to invest and grow*. By their very nature, rigid spectrum caps will deter efficient competitors from expanding, thereby reducing the competitive pressures that other market participants face. Moreover, hard caps on spectrum rights holdings artificially increase costs and decrease investment returns, thus stifling welfare-enhancing investment and innovation. In contrast, a case-by-case analysis with safe harbors provides regulatory certainty for many transactions and allows a wireless service provider to obtain spectrum above the safe harbor where such acquisition does not pose a substantial likelihood of harm to competition.

36. In comments submitted contemporaneously with ours, various commenters suggested alternative versions of a hard cap on spectrum holdings, including a cap on auction transactions but not secondary market transactions, a cap combined with an HHI-based screen for transactions below the cap, and a cap only on spectrum holdings below 1 GHz. As we explain in this section, each of these suggestions is subject to the problems with caps identified in our *Initial Declaration*, as well as additional problems associated with the specific details of each proposal.

A. FREE PRESS'S PROPOSAL TO IMPOSE A SPECTRUM CAP COUPLED WITH A HERFINDAHL-HIRSCHMAN INDEX-BASED SCREEN LACKS ANY SOUND JUSTIFICATION

37. Free Press proposes that the Commission adopt a "first-pass spectrum cap that prohibits any carrier from controlling more than 35 percent of the available spectrum in any local

---

[32] *Israel and Katz Initial Declaration,* ¶ 9 [emphasis in original].

market."[33] For geographic areas in which a transaction would not result in the accumulation of more than 35 percent of available spectrum, Free Press advocates for a screen based on spectrum HHIs: A transaction would be presumed not to be in the public interest if post-acquisition spectrum holdings yielded an HHI of greater than 2500 and the change in HHI was more than 100; a transaction would be presumed to be in the public interest if the change in spectrum HHI was less than 50, and if the change in spectrum HHI was between 50 and 100, there would be no presumption and the impact of the acquisition on competition would be examined closely.[34] This proposal is flawed on multiple dimensions.

1. For all of the reasons explained in our *Initial Declaration,* a spectrum cap would harm competition and consumers

38. All the flaws with a hard cap laid out in our *Initial Declaration* apply with equal force to the Free Press proposal: Adding a screen for transactions that are below the cap does nothing to change the flaws with the cap itself.[35] Moreover, as we explained in our *Initial Declaration*, current marketplace conditions indicate that even a *screen* should likely be set higher than the current level of 1/3 (33.3 percent) of available spectrum. Hence, setting a *cap* at nearly this same level (35 percent) is certainly far too low. Free Press provides no support for a claim that spectrum holdings over 35 percent would necessarily harm consumers and thus no basis for a *per se* ban on spectrum holdings above this level.

39. The same analysis demonstrates that the proposals by NTCH, Inc. to "adopt a bright line spectrum cap" (set at 20 percent of available spectrum) and by the Rural Telecommunications

---

33 Comments of Free Press Inc., *In the Matter of Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269, November 28, 2012 (hereinafter *Free Press Comments*) at 14.

34 *Free Press Comments* at 15 and 16.

35 *Israel and Katz Initial Declaration*, § III.A.

Group, Inc. to implement a "bright line spectrum aggregation limit" (set at 25 percent of suitable and available spectrum and 40 percent of suitable and available spectrum below 1 GHz) would also harm competition and consumers.[36]

2. Free Press's proposed screen has no basis in antitrust policy and would generate many false positives

40. Although Free Press is correct that spectrum-aggregation policies should be grounded in antitrust theory, its own proposal decidedly is not. The mere fact that the proposal embeds an HHI calculation does not ground it in antitrust theory. To the contrary, antitrust theory does not justify the use of a cap, which is effectively a *per se* ban on certain asset transfers. Notably, in the U.S. Department of Justice and Federal Trade Commission's *Horizontal Merger Guidelines* (where HHI is most prominently used), no such cap is used.[37] A proposal to add an HHI-based screen as a second step on top of a cap does not make the proposal consistent with antitrust theory.

41. Under standard antitrust practice, HHIs are used in rough initial screens that are generally applied to firms' share of sales to estimate market concentration, taking into account the various factors that affect firms' abilities to compete. HHI-based screens are not generally applied to ownership percentages for a single input.

---

36 *See*, Comments of NTCH, Inc., *In the Matter of Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269, November 28, 2012, at 1-6; Comments of the Rural Telecommunications Group, Inc., *In the Matter of Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269, November 28, 2012, at 3.

37 The *Horizontal Merger Guidelines* use HHI thresholds and changes in HHIs to establish presumptions about the competitive effects of mergers but do not use them to bar outright any merger, even one to monopoly. (*See*, U.S. Department of Justice and Federal Trade Commission, *Horizontal Merger Guidelines*, August 19, 2010, § 5.3.)

42. Moreover, a safe harbor that says that a firm's spectrum share must be below 35 percent (to avoid the cap) and a transaction must lead to an increase in the HHI of less than 50 points is effectively a huge reduction in the level of the screen, which is a bad idea for all the reasons in our *Initial Declaration*. As one example—if a firm with seven percent of spectrum rights in a given market sold its spectrum to another firm with eight percent of the spectrum rights, that transaction would generate an HHI increase of over 100 points even though it would be highly unlikely to present a competitive problem. There is no sound theoretical or empirical analysis to support the numerical thresholds in Free Press's proposal and, in particular, no attempt to relate these numbers to a foreclosure analysis.

43. Finally, Free Press' HHI-based screen could introduce substantial additional uncertainty in an auction setting. Unlike a share-based screen, under which a carrier could determine whether any particular purchase it might make in an auction would trigger the screen, an HHI-based screen could only be evaluated after one had knowledge of the full set of auction results. Hence, carriers would need to form expectations regarding all other auction winners in a given area in order to determine whether any particular purchase would or would not trip the screen.

B. SPRINT'S PROPOSAL FOR A SEPARATE SPECTRUM CAP FOR HOLDINGS BELOW 1 GHZ LACKS ANY SOUND JUSTIFICATION

44. In its comments, Sprint advocates for the use of a separate spectrum cap for holdings below 1 GHz.[38] Absent a demonstration that large spectrum holdings below 1 GHz can, on their own, lead to foreclosure, such a band-specific cap would harm consumer welfare. This conclusion follows from the fact that such a cap would not address any valid competitive

[38] *Sprint Nextel Comments* at 9.

concern but would raise successful competitors' costs of expanding to offer additional services to consumers.

45. For the reasons presented above with regard to differential weighting, large spectrum holdings below 1 GHz cannot, on their own, lead to foreclosure. In areas where foreclosure based on spectrum holdings is even a plausible issue to consider—markets with dense demand—Professor Peha shows that high-frequency spectrum provides equivalent coverage to low-frequency spectrum. Indeed, AT&T's engineering experts state that high-frequency spectrum is often considered superior in these circumstances.[39] As such, a cap on spectrum holdings below 1 GHz is simply an arbitrary cap on a subset of available inputs, without considering the existence of other, equally valuable inputs, and thus makes no sense as a matter of economics.

46. In addition, as shown in the remainder of this section, data on market outcomes undermine any claim that spectrum below 1 GHz can, on its own, be used to foreclose competition.

1. Data on spectrum holdings and market shares show little correlation between spectrum holdings below 1 GHz and marketplace outcomes

47. As with overall spectrum holdings, evaluating the relationship between concentration of spectrum holdings below 1 GHz and concentration of estimated market shares (both measured via the HHI) makes the key point sharply: There is simply no evidence that increased concentration of spectrum holdings below 1 GHz necessarily yields increased concentration of market shares. Figure 6-A plots the HHIs for spectrum holdings below 1 GHz and estimated market share in the top 50 CMAs. The weak relationship illustrated in the figure is confirmed by a correlation coefficient of only 0.0447, which is very close to zero (*i.e.*, very close to no

[39] *Reed-Tripathi Response* at 9 and 10.

relationship at all). Figure 6-B presents the same analysis for CMAs outside the top 50, which shows that the correlation between the HHIs for spectrum holdings below 1 GHz and the HHIs for estimated market share is negative, with a correlation coefficient of -0.2334. This analysis indicates that that, outside the top 50 CMAs, there is no positive relationship at all between the concentration of spectrum holdings below 1 GHz and downstream-market concentration, and in the top 50 CMAs the relationship is extremely weak.

Figure 6-A

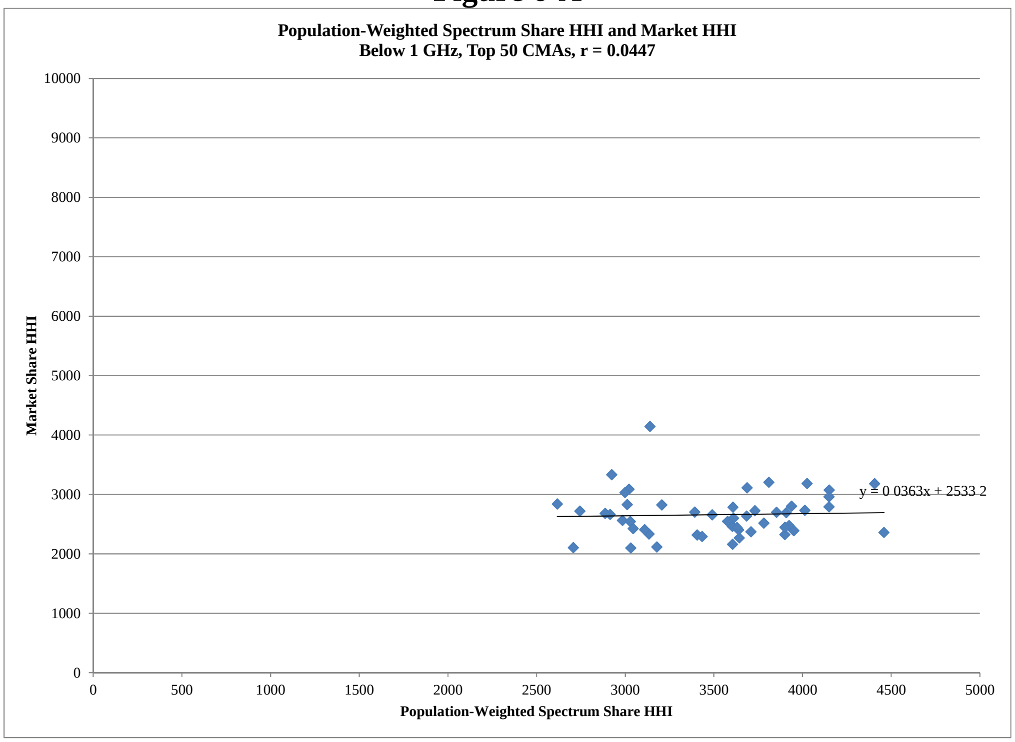
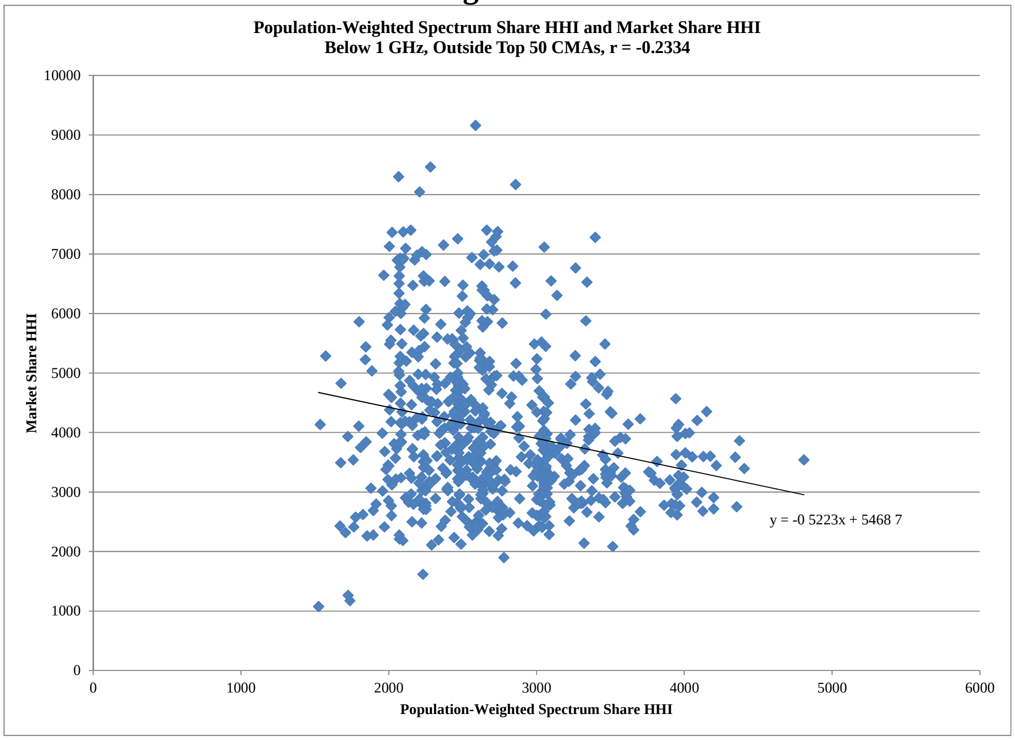


Figure 6-B



48. It should also be observed that, in addition to demonstrating the unsoundness of Sprint's spectrum cap proposal, these data also further support the conclusion that Professor Peha's proposal for a frequency-weighted spectrum screen is unsound. In the less-densely populated CMAs, where Professor Peha contends that low-frequency spectrum is especially important, there is even *less evidence* for a positive relationship between concentration of spectrum holdings below 1 GHz and downstream-market concentration than in the more-densely populated CMAs.

2. There are numerous examples of firms competing effectively using only spectrum above 1 GHz

49. Additional evidence that aggregation of spectrum below 1 GHz cannot be used to foreclose competition comes from the fact that carriers have entered and competed effectively when using *only* spectrum above 1 GHz. An obvious example is T-Mobile USA, which

competes almost entirely with PCS (1900 MHz) and AWS (1700/2100 MHz) spectrum, yet has market share in particular CMAs as high as 50 percent and a nationwide subscriber share of 11.8 percent.[40] [41] Both the Commission staff and the U.S. Department of Justice have argued that T-Mobile USA is an effective and important competitor. In suing to block AT&T's proposed acquisition of T-Mobile USA, the Department of Justice asserted that T-Mobile imposes significant competitive discipline on the marketplace, and the Commission staff reached a similar conclusion.[42]

50. Other examples demonstrate the ability to enter using only spectrum above 1 GHz and thus the impossibility of foreclosing entry by aggregating spectrum below 1 GHz. For example, Leap Wireless (marketing its service under the Cricket brand) entered the wireless marketplace in 1999 in Chattanooga, TN using only PCS (1900 MHz) spectrum.[43] It now competes primarily

---

[40] The Commission's *Spectrum Dashboard* lists T-Mobile as the holder of a Cellular license in one CMA and as the holder of a 700 MHz license in one other CMA. Otherwise, all of T-Mobile's spectrum holdings are in the PCS and AWS bands.

[41] In CMA 304, Joliet, IL, T-Mobile has an estimated market share of 49.5 percent. (*AT&T Market Share Estimates.*) National share of subscribers is from *Fifteenth CMRS Competition Report*, Table 4.

[42] The Department of Justice stated that "AT&T's acquisition of T-Mobile would eliminate the important price, quality, product variety, and innovation competition that an independent T-Mobile brings to the marketplace." (Second Amended Complaint, *United States, et al. v. AT&T, Inc. and T-Mobile USA, Inc.*, Civil Action No. 11-01560 (ESH), September 30, 2011, ¶ 33); and "The proposed merger would eliminate T-Mobile, one of the four national competitors, resulting in a significant loss of competition…." (Second Amended Complaint, *United States, et al. v. AT&T, Inc. and T-Mobile USA, Inc.*, Civil Action No. 11-01560 (ESH), September 30, 2011, ¶ 35.) The Commission Staff in the AT&T-T-Mobile merger stated that "T-Mobile has a history of disruptive competitive conduct that has continued at least up to the time the transaction with AT&T was negotiated. This transaction would result in the elimination of this competitive force from the wireless marketplace." (*Applications of AT&T Inc. and Deutsche Telekom AG for Consent To Transfer Control of the Licenses and Authorizations Held by T-Mobile USA, Inc. and Its Subsidiaries*, Staff Analysis and Findings, WT Docket No. 11-65, November 29, 2011, ¶¶ 21 and 22.)

[43] Leap Wireless International Inc., Form 10K for the year ended August 31, 1999, October 20, 1999, at 2 and 5.

using PCS and AWS (1700/2100 MHz) spectrum, achieving greater than two percent market share in 105 CMAs, and serving a total of 5.9 million subscribers nationwide.[44] [45]

51. MetroPCS provides another example. In 1996, MetroPCS purchased PCS (C-Block) spectrum for Miami, Atlanta, Sacramento, and San Francisco at an FCC auction.[46] It launched service in Miami, Atlanta, and Sacramento in the first quarter of 2002 and added San Francisco, Tampa, Dallas, and Detroit over the next four years, all using PCS spectrum.[47] In 2005, Metro PCS held PCS licenses in five of the ten most populous metropolitan areas in the U.S., and it reached two million customers in February 2006.[48] In 2012, it had greater than two percent of subscribers in 78 CMAs and had approximately 9.0 million subscribers in total,[49] with service offered almost entirely using the PCS and AWS bands.[50]

52. As another example, Clearwire entered the wireless marketplace in 2004 using 2.5 GHz spectrum.[51] Clearwire continues to offer service entirely in the 2.5 GHz band in the United

---

44 According to the Commission's *Spectrum Dashboard*, Leap holds 700MHz licenses in 13 CMAs in Illinois, Indiana, and Wisconsin.

45 *AT&T Market Share Estimates*; Leap Wireless International Inc., Form 10-K for the year ended December 31, 2011, February 21, 2012, at 2.

46 MetroPCS Communications Inc., Form 10-K for the fiscal year ended December 31, 2004, May 12, 2006, at 6.

47 *Id.*, at 4.

48 *Id.*, at 6 and 4.

49 *AT&T Market Share Estimates*; "MetroPCS Reports Third Quarter 2012 Results," press release, October 30, 2012, *available at* http://investor.metropcs.com/phoenix.zhtml?c=177745&p=irol-newsArticle&ID=1751461&highlight, *site visited* December 7, 2012.

50 MetroPCS Communications Inc., Form 10-K for the year ended December 31, 2011, February 29, 2012, at 8. In 2012, Metro PCS offered service using paired PCS and AWS spectrum, although it also held 12 MHz of paired 700 MHz Lower Band A spectrum in the Boston area.

51 Clearwire, Form 10K for the year ended December 31, 2007, March 13, 2008, at 3.

States and ended the third quarter of 2012 with 10.5 million subscribers.[52] Clearwire affirmatively advocates the value of its high-frequency spectrum as a competitive strength due in part to the large ecosystem of devices developed for this band:[53]

> Spectrum in the 2.5 gigahertz band is ideally suited for high-volume wireless data. High-frequency spectrum is much more conducive than low- or mid-band spectrum to meeting the usage and speed requirements of heavy tonnage users in densely populated markets. The 2.5 gigahertz band is also the sweet spot of global TDD LTE evolution. Earlier this year, Clearwire cofounded the GTI consortium with China Mobile, Vodafone, SoftBank and Bharti. Clearwire was the only American carrier included in the consortium. The members of this consortium serve more than 1.3 billion customers, representing 4x the population of the U.S. This means that this group will be driving the lowest possible cost and greatest variety of devices.

53. IDC, a consulting firm commissioned by Clearwire, explained the advantages of the high-frequency spectrum, particularly with respect to the growing use of small cells, as follows:[54]

> In most spectrum bands, operators will struggle with the challenge of deploying small cells in bands that are already covered by macrocell networks. This is likely to lead to interference as customers are within the reach of both wide-area and small cell networks. By contrast, Clearwire could potentially provide a small cell network in a completely different band, eliminating any interference issues with an operator's macro network. Moreover, Clearwire's wide bandwidth enables the company to deploy small cells on a separate channel from its own macrocell assets within the same band. Finally, because of Clearwire's lower propagation vis-à-vis lower spectrum bands, many more small cells will be able to be installed closer together within the company's 2.6GHz spectrum, with much lower interference levels than would be experienced at lower bands.

---

52 Clearwire press release, "Clearwire Reports Third Quarter 2012 Results," October 25, 2012, *available at* http://corporate.clearwire.com/releasedetail.cfm?ReleaseID=716409, *site visited* December 7, 2012).

53 "Clearwire's CEO Discusses Q2 2011 Results," earnings call transcript, *Seeking Alpha*, blog, August 4, 2011, *available at* http://seekingalpha.com/article/284461-clearwire-s-ceo-discusses-q2-2011-results-earnings-call-transcript, *site visited* December 7, 2012.

54 IDC, "Validating the Market for TDD LTE in the US Marketplace," white paper, August 2012, at 7, *available at* http://files.shareholder.com/downloads/CLWR/2144340850x0x608189/1ce5d47e-f996-48d9-9b19-acdb30919a47/IDC_Clearwire_Whitepaper_August_2012.pdf, *site visited* December 4, 2012.

54. Wireless industry analysts concur with Clearwire's assessment on the value of its high-frequency spectrum:[55]

> In our view, it is no longer the case that Clearwire's spectrum around the 2.5GHz frequency is materially less desirable. Largely driven by China Mobile, mobile operators are coalescing around a TD-LTE ecosystem deployed in the 2.3-2.6 GHz frequency range. Generally speaking, these bands offer the opportunity for the largest possible channels which improve the performance TD-LTE (arguments Clearwire has been making for a long time). In many countries, auctions of 2.3GHz and 2.6GHz spectrum are planned (e.g., in Europe, Russia, Asia, and Latin America) or have just taken place (e.g., in India, Sweden, and Norway).

C. T-MOBILE USA'S AND UNITED STATES CELLULAR CORPORATION'S PROPOSALS FOR A CAP ON AUCTION PURCHASES ARE UNWORKABLE AND AGAINST THE PUBLIC INTEREST

55. Commenters including T-Mobile USA and United States Cellular Corporation acknowledge the benefit of case-by-case analysis for secondary market spectrum transactions, but argue that a hard cap should apply to auctions.[56] This proposal defies economic logic for several reasons.

56. First, we argued against a cap in our *Initial Declaration* because of the *outcomes* a cap produces, *e.g.*, preventing pro-competitive spectrum acquisitions and harming incentives to invest and innovate by forcing firms to turn to more expensive alternatives to additional spectrum. These arguments apply to any transaction, whether a primary-market auction or some form of private negotiation in a secondary market. The goal of aggregation policy should be to permit pro-competitive outcomes and prevent only those outcomes that create a real risk of

---

55 Jefferies, *Clearwire Corp.; Econ 101: Scarcity*, analyst report, February 23, 2012, at 6.

56 *T-Mobile Comments* at 7; Comments of United States Cellular Corporation, *In the Matter of Policies Regarding Mobile Spectrum Holdings*, WT Docket No. 12-269, November 28, 2012 (hereinafter, *USCC Comments*) at 6 and 8.

foreclosure, regardless of the institutional form of the transaction. No spectrum cap, whether applied to auctions or secondary market transactions, can accomplish this goal.

57. Second, T-Mobile USA's claim that, whereas auction rules affect all bidders in an auction, Commission policy toward transactions affects only the parties themselves is nonsensical.[57] If multiple parties are potentially interested in a particular spectrum license then they are all affected by who acquires that spectrum, whether that acquisition occurs via auction or private negotiation. More importantly, as we pointed out in our *Initial Declaration*, the relevant question for spectrum aggregation policy is the effect on downstream-market competition, and a cap affects all firms in the industry and all consumers regardless of the institutional form of the transaction.[58]

58. Third, if anything, auctions for newly released spectrum should be subject to more lax restrictions on outcomes than other transactions. Such auctions necessarily increase the amount of spectrum in the market without reducing the spectrum holdings of any firm. As such, to justify restrictions on auction outcomes, one would need to show why increasing the spectrum holdings of certain firms without reducing the spectrum holdings of other firms would lead to foreclosure.

59. Finally, applying one set of rules to auctions and another to private negotiations simply creates arbitrage opportunities. Economics predicts that assets will generally end up in the hands of the users who value those assets most highly. In particular, if the highest-value user of a particular spectrum license were prevented from acquiring the license in an initial spectrum

---

[57] *See*, *T-Mobile Comments* at 8.

[58] *See*, *Israel and Katz Initial Declaration*, § II.B.

license auction, it should be expected to acquire the license from the auction winner through a later, secondary-market transaction.

60. The Commission could attempt to block such secondary-market transactions, but this would then raise difficult and important issues. Specifically, if an eligible bidder has won one or more licenses in an auction, what restrictions—if any—should it face with respect to secondary-market transactions? For example, could it sell its licenses to any willing buyer, or would the buyer have to be an entity that would have been eligible to bid for the license in the primary auction? Alternatively, would a winning bidder for a particular spectrum license be allowed to sell capacity on its network to an ineligible entity or enter into some other sort of network-sharing arrangement?

61. If there were no restrictions on secondary sales, all parties were perfectly informed, and transactions were costless, then an auction-only cap would have no effects: the price of spectrum in the auction would be driven up to the market value, which would be determined by overall supply and demand, and spectrum would be assigned to its highest-value uses. In this case, an auction cap would cause no harm, but it also would have no benefits.

62. In reality, parties are imperfectly informed and transactions are costly, so an auction cap likely *would* cause harm. In particular, the effect of an auction-only cap could be to induce delays in the use of spectrum and to trigger transaction costs because of the need for licenses first to go through the initial assignment process and then be reassigned through secondary-market transactions. In addition, auction-only caps could lead to windfall profits for private entities that bid on spectrum licenses in auctions and then turned around and sold them for a profit to excluded incumbents. These windfall profits would come at the expense of the U.S. Treasury.

63. It might seem evident that the appropriate policy is to ban resale and sharing arrangements with entities that were not themselves eligible to bid for the licenses in the primary auction. However, such a ban would not be a sound policy. Entry is an uncertain proposition. Through experience, entrants frequently learn that they do not have attractive business models and seek to exit the market. The most attractive exit option may be to sell spectrum licenses (and possibly other assets) to incumbent service providers. From a social welfare point of view, selling spectrum licenses to an incumbent through a secondary-market transaction would redirect spectrum to a higher-value use and, thus, generate social benefits. Moreover, by reducing entrants' exit options, a ban on resale transactions could discourage initial entry attempts. That is, a new firm could be discouraged from attempting to enter the market if it knew that it did not have the option of selling its assets to others, including incumbents, if the entrant's business plans did not pan out.

IV. CONCLUSION

64. We reaffirm the findings from our *Initial Declaration* and observe that Professor Peha's analysis supports our conclusions. As to policy proposals submitted contemporaneously with our *Initial Declaration*, we find that competition and consumer welfare would be harmed by implementation of a screen that applies different weights to different spectrum (including a screen that completely ignores spectrum over 1 GHz), by a cap applied specifically to spectrum below 1 GHz, by a cap that applies only to spectrum sold via auction, and by Free Press's proposed 35-percent cap combined with an HHI-based screen for transactions not triggering the cap.

I declare, under penalty of perjury, that the foregoing is true and correct.

Mark Israel

January 7, 2013

I declare, under penalty of perjury, that the foregoing is true and correct.

Michael L. Katz

January 7, 2013